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Clearances and Methods of Protection for Wall and Ceiling Surfaces Exposed to Radiant Heating Appliances

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Clearances and Methods of Protection for Wall and Ceiling Surfaces Exposed to Radiant Heating Appliances

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ABBREVIATION KEY TO TABLES

Wall Protection Systems

Identification	Material		Thickness	
		mm	in	gauge
W	Gypsum wallboard	10	0.375	-
WW	Gypsum wallboard white painted surface			
WB	Gypsum wallboard black painted surface	10	0.375	-
A	Air space	25	1.0	-
AA	Air space	50	2.0	-
C	Inorganic insulation board "C"	6	0.25	-
CC	Inorganic insulation board "C"	12	0.25	-
CB	Inorganic insulation board "C" painted black	6	0.25	-
M	Inorganic insulation board "M"	12	0.50	-
MB	Inorganic insulation board "M" painted black			
Al	Aluminum metal plate	3	0.125	-
AlB	Aluminum plate black painted surface exposed	3	0.125	-
28G	Galvanized metal plate	0.4	0.015	28
28GB	Galvanized metal black painted surface exposed	0.4	0.024	28
24G	Galvanized metal plate	0.6	0.024	24
24GW	Galvanized metal white painted surface			
24GB	Galvanized metal black painted surface exposed	0.6	0.015	24
FG	Fiberglass	25	1.0	-
BR	Brick wall	90	3.50	-

Abbreviation Key to Tables (continued)

Wall Protection Systems		Thickness		
Identification	Material	mm	in	gauge
BRV	Brick veneer	6	0.25	-
P	Wood paneling	18.8	0.75	
T	Wall mat (plaster type)	25	1.0	
S	Wall insulation			

CLEARANCES AND METHODS OF PROTECTION FOR WALL AND CEILING SURFACES EXPOSED TO RADIANT HEATING APPLIANCES

Joseph J. Loftus
Richard D. Peacock

Abstract

The Center for Fire Research in the National Bureau of Standards has evaluated the fire hazard potential associated with the installation and use of solid fuel burning appliances (and chimney connectors) in residential housing.

For this three-part study, mock-up and full scale room walls and ceilings were exposed to radiant energy from chimney connectors and an appliance operated under normal and overfire conditions at various distances or clearances from the room members. Peak surface temperature rise measurements were made on exposed and protected walls and ceilings and comparisons were made with surface temperature rise limitations established by building and fire codes.

In the testing program, a total of 19 different thermal barriers or protection systems were evaluated and a number were found capable of providing adequate thermal protection. Particularly effective were those systems which used a sheet metal plate or two sheet metal plates with an insulative layer between them mounted in front of a wall or ceiling and separated from the room surface by a 25 mm (1 in) air space. This provision for air to circulate freely between a room member and its protector proved to be an extremely important factor in providing for increased fire safety.

Based on these findings, recommendations are made which building and fire code officials may find useful in preparing fire safety codes and regulations designed to protect the consumer from personal and property damage caused by unwanted fires.

Key words: ceilings; chimneys; fire codes; fire protection; fire tests; interior finishes; radiant energy; residential buildings; stoves; walls.

1. INTRODUCTION

The Consumer Product Safety Commission and the Department of Energy have sponsored research at the Center for Fire Research in the National Bureau of Standards to investigate the fire safety of wood burning appliances (stoves) used for space heating in single family homes and similar residences. The objective of this work is to reduce the number of house fires that occur every year in the United States as a result of faulty heating stove and chimney connector installations.

The testing program described in this report was divided into three parts:

- Part I. Systems for Protection of Wall Surfaces Exposed to Radiant Appliances.
- Part II. Systems for Protected Wall and Ceiling Surfaces Exposed to Heating Appliance Chimney Connectors.
- Part III. Full Room Validation of Wall and Ceiling Devices for Heating Appliance and Chimney Connector Systems.

2. BACKGROUND

With the advent of high fuel costs, increasing numbers of consumers have turned to using alternate fuel sources for home heating; wood, in particular, is being used in place of traditional gas and oil fuels. The unfortunate part of this solution, however, is that the number of house fires has shown a marked increase because many consumers and homeowners are making stove installations (in their homes) that are clearly in violation of building and fire safety code regulations.

The main problem lies in the fact that wood is a combustible material and that most homes are made with "stick construction"; that is, wood is used in framing out the house. Wood has an ignition temperature of about 200°C (392°F); however, there have been reports of wood ignition after long term conditioning to exposure temperatures as low as 60 to 108°C (140 to 226°F) [1,2][1]. Wood framing in close proximity to a hot chimney surface is thus highly susceptible to ignition because chimney surfaces can reach temperatures as high as 240°C (464°F) due to the fact that flue gas temperatures in lined chimneys can easily exceed 592°C (1100°F).

On this basis, codes recommend that wood should not be exposed to temperatures higher than 100°C (212°F) and that wood framing around chimneys be separated from the chimney by an air space of at least 50 mm (2 in) to be considered safe. Concerning clearances between combustibles and solid fuel burning appliances (including chimney connectors), the codes recommend that the radiant heating appliances be located at least 914 mm (36 in) away from adjacent surfaces and that distances between single wall, metal chimney connector pipes and combustibles be 457 mm (18 in). The National Fire Protection Association considers these clearances to be adequate for maximum appliance surface temperatures ranging from 300 to 350°C (572 to 662°F); however, for reduced clearances to combustibles, two materials are listed as suitable for use as thermal barriers or protective devices - asbestos-containing mill boards (in various thicknesses) and sheet metal. Health concerns with asbestos, however, strongly suggest against its use.

In previous reports [1-4] submitted to the Department of Energy and to the Consumer Product Safety Commission on the fire safety of wood-burning appliances, CFR has presented information on a survey of fire incidents involving wood-burning appliances and a review of codes and standards dealing with solid fuel appliances. These reports provided the basis for research on proper clearances between wall lining surfaces and wood-burning appliances and on protective devices that may be used to allow for reduced clearances.

---

[1] Numbers in brackets refer to literature references listed in section 24 at the end of this report.

The following three part report details the results of such a research effort designed to study the effects that clearances and protective devices have on surface temperatures of room walls and ceilings exposed to radiant energy from hot appliance and chimney connector pipe surfaces.

3. REVIEW OF PREVIOUS WORK

3.1 Minimum Safe Clearance and Temperature Specifications in Existing Codes and Standards

Recommendations for minimum acceptable clearances to combustible materials for the installation of chimneys, chimney connectors, and appliances are specified in the various model codes and recommended practice manuals [2,5-13]. For simplicity and ease of enforcement, a single (hopefully conservative) clearance is given for each type of appliance installed without protection. No allowance is made for the size, heat output, heat transfer characteristics, or other features unique to individual models. Similarly, only a few, specific methods of protection employed to allow reduction of these clearances are recommended. Typically, 914 mm (36 in) of clearance is specified between radiant heaters and unprotected combustible construction in the codes. For circulating heaters, clearances of 610 mm (24 in) from the front of the appliance and 305 mm (12 in) from the sides and back of the appliance are recommended [13]. For single wall metal chimney connectors, 457 mm (18 in) is usually recommended as a minimum clearance [12].

The experimental basis for these code requirements, however, is not quite clear. Several experimental studies have been carried out to determine minimum acceptable clearances to combustible materials. Voigt [14], in a 1933 publication, recommends a minimum clearance of 305 mm (12 in) for chimney connectors 229 mm (9 in) in diameter. A more extensive study, performed by Underwriters Laboratories in 1943 [15], presents minimum safe clearances for both unprotected surfaces and surfaces protected by various methods. Distances at which a maximum temperature rise of 50°C (90°F) above room temperature is reached are presented as a function of the temperature of the exposed face of a heat producing appliance. The relative protection afforded by various materials used as heat barriers between the appliance and combustible surface was also examined. Lawson, Fox, and Webster [16] and Lawson and Simms [17] studied the heating of wall panels and wood by radiation. With experimentation and theoretical predictions, they present safe clearances between flue pipes and wall surfaces as a function of the pipe diameter and the pipe surface temperature. To maintain a maximum wall temperature of 100°C (212°F), a 152 mm (6 in) pipe should not exceed 350°C (662°F) in surface temperature at a clearance of 456 mm (18 in) [16].

These experimental studies established limits for two important parameters: appliance surface temperature and clearance to combustibles for unprotected and protected surfaces. Maximum appliance surface temperature for the appliances studied ranged from 300 to 350°C (572 to 662°F). Minimum safe wall clearance for unprotected surfaces range from 805 to 914 mm (12 to 36 in). Most of the current code provisions are only adequate for maximum appliance surface temperatures up to 300 to 350°C. In addition, all the methods of wall protection specified in the model building codes use two materials: asbestos millboard in various thicknesses and sheet metal. With the current health concerns with the use of asbestos, few alternatives are left for wall and floor protection.

3.2 Temperatures Developed in Heating Systems

Tests made with prefabricated porcelain-enameled metal chimneys for solid or liquid fuel furnaces [18,19] established a limiting temperature rise of 190°C (374°F) on the outer surface of the chimney for a flue gas temperature of 537°C (1000°F). With this limitation, wood framing spaced 50 mm (2 in) or more away from the chimney was considered safe. Satisfactory insulation of the chimneys to reduce the outer surface temperatures to acceptable levels was obtained with asbestos paper plies totaling about 45 mm (1-3/4 in) in thickness. In the same study, some asbestos-cement pipe coverings were also found to reduce heat transmission to the extent required for safety of nearby combustibles.

To establish performance requirements for lightweight prefabricated chimneys, tests were conducted with lined and unlined masonry chimneys having 102 mm (4 in) thick walls [20]. Hazardous conditions on wood framing spaced 5 mm (2 in) away from the chimney were noted with a continuous flue gas temperature of 482°C (900°F) for the unlined chimney and 592°C (1100°F) for the lined chimney. However, these hazardous conditions were not reached in the lined chimney tests until after 13 hours. In order to study operating conditions with typical fuels, a number of firing tests [21] were conducted with heating appliances known to give high flue gas temperatures, using wood and soft coal as fuels. With a coal-fired, jacketed type heater, gas temperatures ranging from 648°C to 704°C (1200°F to 1300°F) were measured for an hour or more in the flue at the ceiling level above the heater.

Lawson et al [16] present the results of tests to measure surface temperatures of flue pipes to validate theoretical predictions. Measured for a variety of flue systems using solid fuels—mostly coal and coke—they report temperatures of about 150°C (300°F) under "normal conditions" and temperatures as high as 815°C (1500°F) under overload conditions.

Fox and Whittaker [21] report temperatures on metal flues of several heating appliances over a range likely to be encountered in normal use. Maximum flue pipe surface temperatures ranged from 704 to 815°C (1300 to 1500°F) at the appliance flue outlet, 360 to 510°C (680 to 950°F) at a distance of 0.91 m (3 ft) from the appliance flue outlet and 287 to 326°C (550 to 620°F) at a distance of 1.83 m (6 ft) from the appliance flue outlet.

Shoub [18] concludes that combustible materials will be ignited if maintained in continued contact with a masonry chimney of 120 mm (4-3/4 in) wall thickness and with flue gas temperatures of 398°C (750°F).

Current Underwriters Laboratories test procedures for prefabricated chimneys require testing of chimney assemblies with hot flue gases [22]. Flue gas temperatures of 537°C (1000°F) are maintained until steady-state conditions are reached, followed by 759°C (1400°F) for 1 hour and 928°C (1700°F) for 10 minutes. These conditions are intended to simulate worst-case conditions.

In tests for the Department of Energy [2], temperatures ranging from 297 to 436°C (567 to 817°F) during normal operation and 377 to 693°C (712 to 1281°F) during overload conditions were noted on the surfaces of late model, wood-burning appliance surfaces.

In the present study, peak appliance surface temperatures are employed.

3.3 Limiting Safe Temperatures on Combustible Surfaces

Listings of heat producing appliances and methods for setting clearances between appliances and combustible surfaces are based on Underwriters Laboratories listings:

- maximum temperature rise of 65°C (117°F) above room temperature on exposed surfaces; and,

- maximum temperature rise of 50°C (90°F) above room temperature on unexposed surfaces such as beneath the appliance, floor protector, or wall-mounted shield [24].

These requirements are based on the fact that, while the ignition temperature of wood products is generally quoted to be on the order of 200°C (392°F) [12], wood that is exposed to constant heating over a period of time may undergo a chemical change resulting in a much lowered ignition temperature and increased potential for self-ignition. Results of some of the research describing this phenomenon are enumerated below.

Mitchell [25] presents data on wood fiberboard exposed to temperatures as low as 109°C (228°F) that resulted in ignition after prolonged exposure. MacLean [26,27] reports charring of wood samples at temperatures as low as 93°C (200°F). He concludes that wood should not be exposed to temperatures appreciably higher than 66°C (150°F) for long periods. McGuire [28] suggests that the maximum safe temperature on the surface of a combustible material adjacent to a constant heat source should be no more than 100°C (212°F).

Clearly, the ignition of wood at moderately elevated temperatures is a complex phenomenon; the time of exposure is indeed an important parameter [29, 30]. While exact limits recommended in the literature vary due to exposure time and details of the tests conducted, the numerous documented fires involving the ignition of wood members near low pressure steam pipes [31] suggest an upper temperature limit for wood exposed to long-term low-level heating should not be appreciably higher than 100°C (212°F).

Part I. Systems for Protecting Wall Surfaces Exposed to Radiant Appliances

4. WALL PROTECTION SYSTEMS

Table 1 presents sketches of the four unprotected walls and the 19 different wall protection systems evaluated in this study. The systems were especially designed to obtain as wide a spectrum of information as possible on temperature protection devices for walls exposed to radiant heat from home heating appliances. As shown, gypsum wallboard served as the base material for each of the systems. This particular wallboard was chosen because of its widely accepted use in room wall construction found in homes and other dwelling places. For 12 of the 23 systems, the wallboard surfaces were painted black to represent worst case conditions of dirt accumulation or paint choice. In 11 of the systems, protector surfaces were also painted black.

The exposed surface of each wall system measured 1.2 x 1.2 m (4 x 4 ft) and the panels were mounted vertically with an allowance made for a 25 mm (1 in) airspace from the floor.

For the purposes of brevity, a key on the page following table 1 identifies the various components used for the wall protection systems shown in table 1 and in system descriptions throughout this report. The following outlines the rationale used in the selection of the particular wall systems for this evaluation study.

1. Compare surface temperature rise on unprotected and unpainted base gypsum wallboards "W" (no. 2 and no. 7) with unprotected and black painted "WB" wallboards (no. 11 and no. 16).

2. Determine the protection afforded to the base wallboard material by metal plate/air space(s) combinations: no. 1 (W,A,Al), no. 6 (W,A,28G), and no. 9 (W,AA,28G).

3. Determine the effect of black painted metal plate(s) and air space(s) combinations on unpainted wallboard surface temperatures: no. 8 (W,A,28GB) and no. 10 (W,A,28GB,A,28GB).

4. Determine the effect of black painted metal plate(s) and air space(s) combinations on wallboard surface temperatures: no. 12 (WB,A,24GB), no. 13 (WB,AA,24GB), no. 14 (WB,A,24GB,A,24GB), and no. 15 (WB,A,AlB).

5. Determine the effect of protection systems (attached directly to base wallboards) on wallboard surface temperatures: no. 3 (W,M), no. 5 (W,M,28G), no. 17 (WB,FG,CB), and no. 22 (WB,BRV).

6. Determine the effect of unpainted insulation boards and a brick wall offset by air space from the base wallboard on wallboard surface temperatures: no. 4 (W,A,M), no. 18 (WB,A,CB), and no. 23 (WB,A,BR).

7. Determine the protection offered to black painted wallboards by black painted metal plate sandwich panels separated by air space from the wallboard (exposed side of sandwich blackened). no. 19 (WB,A,24GB, FG,24GB), no. 20 (WB,A,24GB,C,24GB), and no. 21 (WB,A,24GB,CC,24GB).

Since "worst-case conditions" were created by black painted surfaces, it was expected that the effectiveness of the different wall protection systems might be judged by their ability to reflect or absorb radiation and/or to dissipate absorbed radiation. For insulating materials, the following properties were noted:

Thermal Properties of Insulating Materials Used in Wall Protection Systems

Component	Material	Density (kg/m^3)	Thermal Conductivity (W/mK)
M	Calcium Silicate Board	769	0.14
CB	Refractory Fiber Board	384	0.13
FG	Fiberglass	60	0.037
BR	Brick	2600	0.8
BRV	Brick Veneer	2600	0.8

5. TEST APPARATUS

A mock-up heating stove apparatus was constructed for the test series. The stove enclosure was fabricated with 6 mm (1/4 in) thick steel plates and measured 500 x 500 x 500 mm (20 x 20 x 20 in). The fire box was supported 350 mm (14 in) from the floor by steel angles attached to the box. The test apparatus, illustrated in figure 1, has a radiant panel mounted on the floor of the stove enclosure. The panel consists of a porous refractory material mounted in a cast-iron frame allowing for the combustion of gas over its surface which measures 304 x 457 mm (12 x 18 in). Natural gas mixed with air was used for the tests. Venting for the stove was provided by a conventional 152 mm (6 in) diameter stovepipe system.

Figure 2 shows the location of five 24-gauge, 0.5 mm (0.020 in) chromel-alumel thermocouples attached to the irradiating surface of the stove facing the test walls. One thermocouple was located at the center of the 500 x 500 mm (20 x 20 in) surface, and the four remaining thermocouples were positioned at 152 mm (6 in) distances from the center thermocouple in both the horizontal and vertical planes. The thermocouples were attached to the steel plate by metal washers fastened to the plate with sheet metal screws.

Figure 3 shows the thermocouple system (24 gauge chromel-alumel), used to monitor the temperatures generated on the irradiated and protected wallboard surfaces of the wall systems during tests. One thermocouple was mounted at the center of each test panel (measuring 1.2 x 1.2 m) and from this thermocouple additional thermocouples were positioned in horizontal and vertical lines at distances of 152, 304, and 457 mm (6, 12, and 18 in) from the center. For temperature averaging purposes, equidistant thermocouples were connected in parallel. Ambient air temperature in the test room was measured by a thermocouple shielded in a 152 mm (6 in) aluminum pipe located 1.2 m (4 ft) from the stove.

6. TEST PROCEDURES

Wall test panels were mounted in a vertical position and stove to wall clearances were adjusted over the following six distances: 914, 610, 457, 304, and 76 mm (36, 24, 18, 12, and 3 in). (Note: the clearance established by Fire Codes [8], i.e., 914 mm (36 in), was used as the starting point for tests.) With the center thermocouples on the stove and wall panel surfaces in alignment, the stove's gas radiant panel was fired. Gas flows to the panel were monitored over a range of 14 to 76 ℓ/s (30 to 160 SCFM) to provide the desired test temperature levels on the stove surface; i.e., 150, 200, 250, 300, and 350°C. The range of these temperatures is based on previous work with actual wood-burning appliances [2]. Functions describing the relation between wall surface temperature and distance are derivable from theory and these are discussed in detail in reference [23].

Stove surface temperatures were quickly and easily maintained; however, the irradiated wall test surfaces did not reach a reasonable level of constancy until 2 to 3 hours of exposure time had passed. Typically, a test was started with the test wall 914 mm (36 in) away from the radiating stove surface. When the temperature on the wall reached peak value, that temperature was recorded for the test location. The wall was then moved to the next closer test location and the testing procedures were repeated exactly. The peak temperature rise values for each test location and stove temperature were used for data analysis and plotting.

The time required for obtaining a complete set of data for the temperature and clearance tests was approximately 1 to 1-1/2 working days.

7. TEST RESULTS AND DISCUSSION

Figures 4 to 8 show the temperature rise (peak surface temperature minus room temperature) obtained for tests on each of the 23 gypsum wallboard surfaces (unprotected and protected) at six different clearances between the wall and stove surface, i.e., 914, 760, 610, 457, 304, and 76 mm (36, 30, 24, 18, 12, and 3 in) and five different stove temperatures, 150, 200, 250, 300, and 350°C (270, 392, 482, 572, and 662 F). As expected, the smallest temperature rise values were obtained for the 914 mm (36 in) clearances and the highest for the 76 mm (3 in) separations.

For discussion and comparison purposes, attention will be focused on the peak temperature rise data listed in table 2 for worst case conditions: 350°C stove surface temperature and 76 mm (3 in) stove-wall clearance. An analysis of the test results showed the following.

7.1 Unprotected Gypsum Wallboard - Painted Versus Unpainted Surfaces

		Peak Wallboard Temperature Rise, °C
No. 2 (W)	Unpainted Wallboard	68*
No. 7 (W)	Unpainted Wallboard	Ignition**
No. 11 (WB)	Black painted wallboard	Ignition**
No. 16 (WB)	Black painted wallboard	Ignition**

*250°C (482°F) test @ 304 mm (12 in) - not tested @ 350°C (662°F)

**Because of ignitions, these samples are not listed in table 2.

For worst case exposures, the paper surface (painted and unpainted) of the gypsum wallboard ignited and flamed for 3 to 12 minutes. Surface damage amounted to an approximate 304 mm (12 in) diameter circle of paper being burned away before extinguishment occurred. Tests at the 304 mm (12 in) clearance showed that the effect of the black painted surface on temperature rise was not in evidence.

7.2 Effect of Metal Protector and Air Space on Wallboard Surface Temperature

Peak temperature rise data for wallboard surfaces protected by air space(s) and unpainted metal plates are listed below:

	Temperature Rise, °C
No. 1 (W,A,Al)	-2*
No. 6 (W,A,28G)	1
No. 9 (W,AA,28G)	0

*300°C (572°F) test - not tested at 350°C (662°F). Negative rise indicates a lower surface temperature on protected board than recorded for ambient room conditions.

Results of these tests show that no appreciable surface temperature rise was recorded for the air space and metal plate protected wallboard surfaces.

7.3 Effect of Black Painted Metal Protector and Air Space on Wallboard Surface Temperature

Two systems were tested using a black painted metal protector in front of an unpainted wallboard:

	Temperature Rise, °C
No. 8 (W,A,28GB)	80
No. 10 (W,A,28GB,A,28GB)	0

The contribution of a black painted metal protector plate to unpainted wallboard surface temperature rise is shown in these tests where the plate surface in system no. 8 registered 230°C (446°F) and the protected wallboard developed a temperature rise of 80°C (176°F). By comparison, an unpainted protector plate in system no. 6 (Section 7.2) showed a surface temperature of 107°C while its protected wallboard showed temperatures at the room temperature level.

System no. 10 clearly showed the advantage of using an additional air space and metal plate protector for wallboard thermal protection. For no. 10 the temperature rise on the wallboard surface was negligible while no. 8 (which had a single air space and metal plate) allowed an 80°C (176°F) temperature rise. In both cases the protector plate surfaces were painted black.

7.4 Effect of Black Painted Metal Protectors and Air Space on Black Painted Wallboard

Four systems tested consisted of black painted metal protectors with a black painted wallboard surface:

	Temperature Rise, (°C)
No. 12 (WB,A,24GB)	112
No. 13 (WB,AA,24GB)	52
No. 14 (WB,A,24GB,A,24GB)	0
No. 15 (WB,A,A1B)	181

For these tests, a thicker metal plate [24 gauge (0.024 in.)] was used for wallboard protection. A comparison of results for system no. 14 (24 gauge) with system no. 10 (28 gauge) (Section 7.3) however showed no temperature rise on the wallboard surfaces, and the board in no. 14 was painted black.

For system no. 15, the protector was an 8 gauge (0.128 in) aluminum metal plate painted black. This plate developed a surface temperature of 263°C (505°F) and the black painted wallboard separated from the plate by an air space showed a surface temperature rise of 181°C (357°F). In this case, the metal plate thickness did appear to contribute significantly to wallboard temperature rise.

The advantage of using an additional 25 mm (1 in) air space between the wallboard and protector plate was demonstrated by tests on system no. 13 where the wallboard showed a temperature rise of 52°C (125°F). By comparison, the wallboard in system no. 12 protected by a single air space and metal plate showed a temperature rise of 112°C (234°F), or 60°C (140°F) higher than the board in no. 13.

The effects of black surfaces on wallboard surface temperature rise were exhibited by the comparison of results for system no. 12 with those obtained for system no. 8 (Section 7.3). The wallboard in no. 8 had an unpainted surface and was protected by a black painted 28 gauge plate. Its temperature rise was 80°C. The wallboard in system no. 12 was painted black and its 24 gauge protector plate was painted black. Its temperature rise was 112°C (234°F). Here the higher temperature rise can be attributed to the combination of a black painted board surface and a black painted and thicker metal plate protector.

7.5 Effect of Protective Devices Attached Directly to Wallboard

Results of tests on four different wall systems are listed as follows:

	Temperature Rise, °C
No. 3 (W,M)	136*
No. 5 (W,M,28G)	6
No. 17 (WB,FG,CB)	99
No. 22 (WB,BRV)	292

*300°C(572°F) test - not tested at 350°C (662°F)

The value of a metal plate-insulation board combination attached to the wallboard in system no. 5 was evidenced by the low temperature rise (6°C) observed for the wallboard. The ability of the unpainted metal surface to reflect heat combined with the insulation qualities of the insulation board helped produce the low temperature value. System no. 3 used the same insulation board but did not have the benefit of a metal cover plate and thus the protected wallboard surface temperature rise reached 136°C (277°F) even at an exposure temperature of 300°C (572°F). System no. 17 used a fiberglass and "C type" insulation board package to protect a painted wallboard. The wallboard material developed a temperature rise of 99°C (210°F).

In tests on system no. 22, the 6 mm (1/4 inch) thick brick veneer attached to the wallboard developed a glow on its surface and caused the paper

7.6 Effect of Air Space Combined with Protective Insulating Boards and a Brick Wall on Wallboard

Results of tests on three different wall systems are listed as follows:

	Temperature Rise, °C
No. 4 (W,A,M)	30*
No. 18 (WB,A,CB)	67
No. 23 (WB,A,BR)	57

*300°C (572°F) test - not tested at 350°C (662°F)

The advantage of using an air space for helping to reduce wallboard surface temperatures was again illustrated by a comparison of system no. 4. with system no. 3 (Section 7.5). With the air space in no. 4, the wallboard showed a temperature rise of 30°C. However, in no. 3 where no air space was used the wallboard developed a temperature rise of 136°C (277°F) for exposures at 300°C (572°F). System no. 18 used a black painted "C type" insulation board and air space to protect a black painted wallboard. Here the wallboard showed a temperature rise of 67°C (153°F).

The solid brick wall in system no. 23 registered a peak surface temperature of 342°C (684 F) and the painted wallboard separated from the wall by 25 mm (1 in) air space showed a temperature rise of 57°C (135°F).

7.7 Effect of Black Painted Metal Sandwich Panels and Air Space on Wallboard Surface Temperature

Results from tests on three different wall systems are listed as follows:

	Temperature Rise, °C
No. 19 (WB,A,24GB,FG,24GB)	7
No. 20 (WB,A,24GB,C,24GB)	11
No. 21 (WB,A,24GB,CC,24GB)	10

Each of the sandwich panels was successful in maintaining low temperature rise on the protected wallboard surfaces. Results indicate negligible differences between the different sandwich fill materials and their effect on wallboard temperatures.

8. SUMMARY OF RESULTS

A total of 23 different wall systems (19 protected and 4 unprotected) were evaluated for their ability to resist radiant energy exposure from a simulated wood fired stove operated at five different temperature levels ranging from 150 to 350°C (302 to 662°F). Clearances between the walls and the stove were varied from 76 to 914 mm (3 to 36 in).

Figures 4 to 8 show temperature rise on the base gypsum wallboard surfaces as determined for each of the exposure tests at the various clearances.

Table 2 lists the wall system number, peak temperatures for the protector and wallboard surfaces, the test room temperature, and the temperature rise for the protector and wallboard surfaces above room temperature. Except where noted, all of these values are for "the worst-case" conditions of 350°C (662°F) stove surface temperature and stove to wall surface clearances of 76 mm (3 in).

The unprotected and unpainted gypsum wallboard systems, no. 2 and 7, and black painted unprotected gypsum wallboards, 11 and 16, are not listed. This is because the paper surfaces on each of the boards ignited and burned away during tests at the 300°C (572°F) exposure.

The criteria used for evaluation of data listed in table 2 were based on recommendations made by Underwriters Laboratories [24] that the upper limit for temperature rise above room temperature on unexposed surfaces, such as beneath an appliance, floor protector, or wall mounted shield, be 50°C (90°F). They also cite a temperature limit of 65°C (117°F) on exposed combustible surfaces, but this limit was not considered applicable to the protector surface data also listed in table 2 since the protectors were made of noncombustible materials.

9. OBSERVATIONS

Based on an analysis of the data listed in table 2 the following observations are made.

1. A total of 8 systems were successful in limiting wallboard surface temperature rise to less than 50°C for tests under worst-case conditions. (Missing from this listing is system no. 1 (W,A,Aℓ) which was only tested at the 300°C exposure and showed a negligible surface temperature rise. If tested at 350°C this system would clearly have passed the test exposure.)

	Temperature Rise, °C
No. 5 (W,M,28G)	6
No. 6 (W,A,28G)	1
No. 9 (W,A,A,28G)	3
No. 10 (W,A,28GB,A,28GB)	0
No. 14 (WB,A,24GB,A,24GB)	0
No. 19 (WB,A,24GB,FG,24GB)	7
No. 20 (WB,A,24GB,C,224GB)	11
No. 21 (WB,A,24GB,C,C,24GB)	10

2. Except for system no. 5 all of the systems used air space(s) between the wallboard and protectors.

3. Systems with two air spaces and protector plates provided the greatest thermal protection for the wallboard.

4. Systems with sandwich panels as protectors showed temperature rise values ranging from 7 to 10°C (13 to 18°F).

5. Systems failing to meet the 50°C temperature rise limitation were:

	Temperature Rise, °C
No. 8 (W,A,28GB)	80
No. 12 (WB,A,24GB)	112
No. 13 (WB,AA,24GB)	52
No. 15 (WB,A,AlB)	181
No. 17 (WB,FG,CB)	99
No. 18 (WB,A,CB)	67
No. 22 (WB,BRV)	292
No. 23 (WB,A,BR)	57

Systems allowing the wallboard surface temperature to rise above 100°C (212°F) were nos. 12, 15 and 22. In no. 22 the simulated brick veneer sample actually developed smoldering. In no. 15 the 8 gauge aluminum plate painted black developed a temperature of 263°C (505°F).

6. Both unpainted and painted gypsum wallboard surfaces in systems nos. 2, 7, 11, and 16 respectively, ignited when the unprotected surfaces were tested at 350°C (662°F) exposures. Damage, however, was limited to the exposure area.

7. Three systems nos. 1 (W,A,Al), 3 (W,M), and 4 (W,A,M) were not tested at 350°C.

on the wallboard also to ignite and glow and thus a peak temperature of 292°C (558°F) was observed.

8. Figure 9 summarizes the clearance test results for 15 of the wall systems. An examination of this figure shows that seven systems provided acceptable wallboard surface temperature rise for clearance reductions to 76 mm (3 in) between the stove and wall surfaces. Six systems needed 304 mm (12 in) clearance to provide for code acceptable performance. One system needed (no. 17) (WB,FG,CB) 457 mm (18 in) clearance and system (no. 22) (WB,BRV) failed tests even when the clearance was 914 mm (36 in).

10. CONCLUSIONS

1. Room walls in proximity to home heating appliances need thermal protection from irradiating hot stove surfaces.

2. The most efficient wall protection systems found in these tests were those which used an air space 25 to 51 mm (1 to 2 in) in combination with unpainted metal plate protectors or an air space combined with sandwich panels consisting of a noncombustible board or fiberglass material between two metal plates. Such systems allowed for clearance reductions to as low as 76 mm (3 in) between walls and stove surfaces at 350°C (662 F).

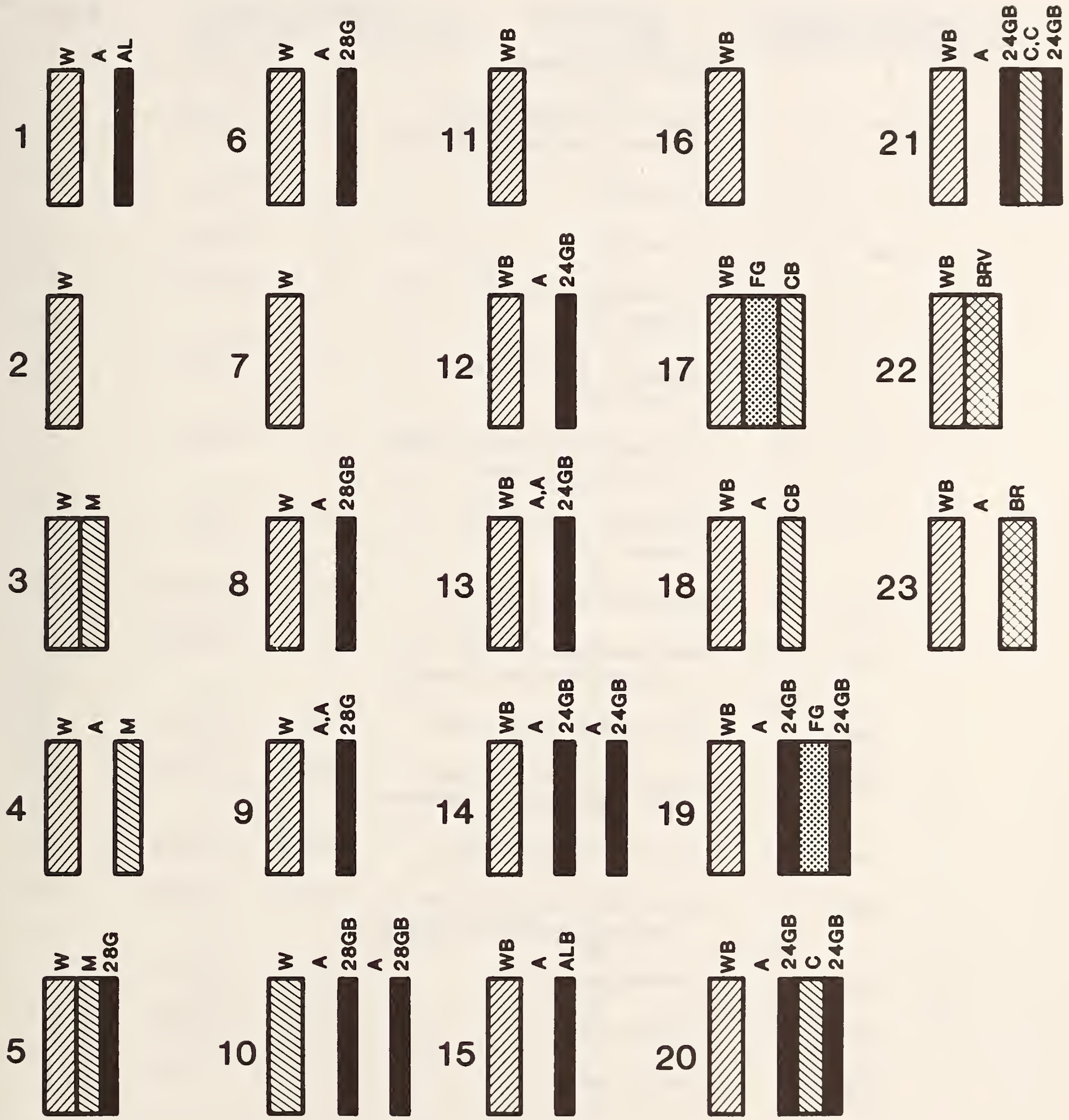
3. The wall protection systems using a single metal plate and air space were found to require 304 mm (12 in) clearances from the stove when their exposed surfaces were painted black.

4. Wall systems using 2 air spaces in combination with 2 metal plates permit clearance reductions to 76 mm (3 in) at the 350°C (662 F) exposure even when the metal plate surfaces and wallboard are painted black.

5. A brick wall required 304 mm (12 in) clearance from a stove when the separation between the brick wall and the protected wall was a 25 mm (1 in) air space.

6. Thin masonry veneer attached directly to a combustible wall affords little thermal protection to the wallboard material.

Table 1. Twenty-three Wall Protection Systems Tested



KEY to Table 1

Wall Protection Systems		Thickness		
Identification	Material	mm	in	gauge
W	Gypsum wallboard	10	0.375	-
WB	Gypsum wallboard black painted surface exposed	10	0.375	-
A	Air space	25	1.0	-
AA	Air space	50	2.0	-
C	Inorganic insulation board "C"	6	0.25	-
CC	Inorganic insulation board "C"	12	0.50	-
CB	Inorganic insulation board "C" painted black	6	0.25	-
M	Inorganic insulation board "M"	12	0.50	-
Al	Aluminum metal plate	3	0.125	-
AlB	Aluminum plate black painted surface exposed	3	0.125	-
28G	Galvanized metal plate	0.4	0.015	28
28GB	Galvanized metal black painted surface exposed	0.4	0.024	28
24G	Galvanized metal plate	0.6	0.024	24
24GB	Galvanized metal black painted surface exposed	0.6	0.015	24
FG	Fiberglass	25	1.0	-
BR	Brick wall	90	3.50	-
BRV	Brick veneer	6	0.25	-

Table 2. Temperature Rise Above Room Temperature for Protector and Gypsum Wallboard Surfaces for "Worst-Case" Conditions*

Wall System No.	Peak Temperature°C		Temperature °C	Temperature Rise °C	
	Protector	Wallboard	Test Room	Protector	Wallboard
5	55	43	37	18	6
6	107	37	36	71	1
8	230	120	40	190	80
9	158	38	35	123	3
10	305	38	38	267	0
12	333	152	40	293	112
13	317	86	34	283	52
14	305	35	35	270	0
15	263	214	33	230	181
17	360	129	30	330	99
18	300	100	33	267	67
19	359	34	27	332	7
20	360	40	29	331	11
21	367	39	29	338	10
22	375	328	36	339	292
23	342	89	32	310	57
1 **	96	37	39	57	-2
3 **	203	174	38	165	136
4 **	207	72	33	174	39

*Worst case conditions = stove surface 350°C (662°F), stove-wall clearance 7.5 cm (3 in).

**Stove surface 300°C (572°F)

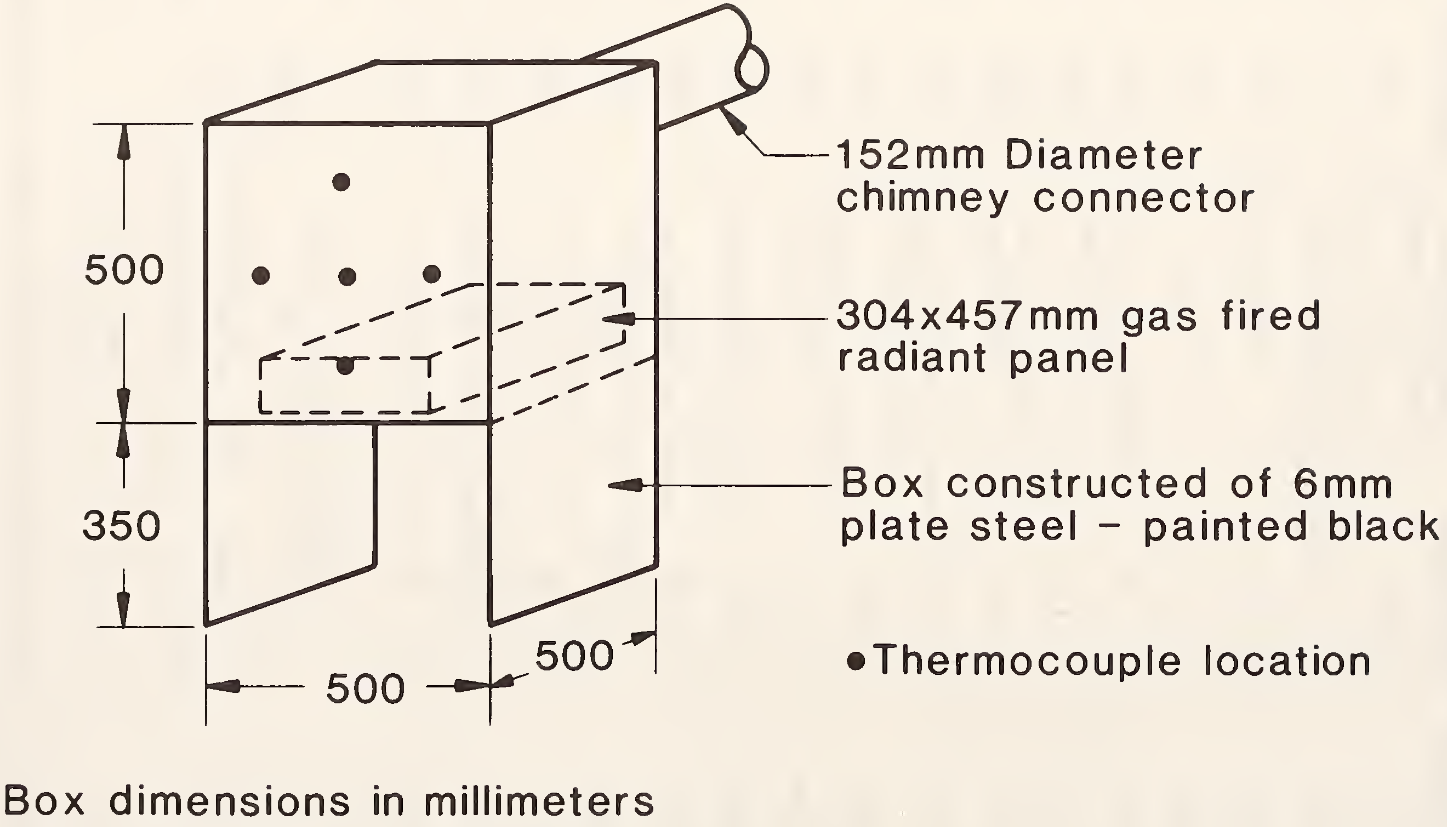

152mm Diameter chimney connector
304x457mm gas fired radiant panel
Box constructed of 6mm plate steel – painted black
●Thermocouple location
500
350
500
500
Box dimensions in millimeters

Figure 1. Appliance Construction Details for Gas Fire Stove Used in Wall Protection Tests

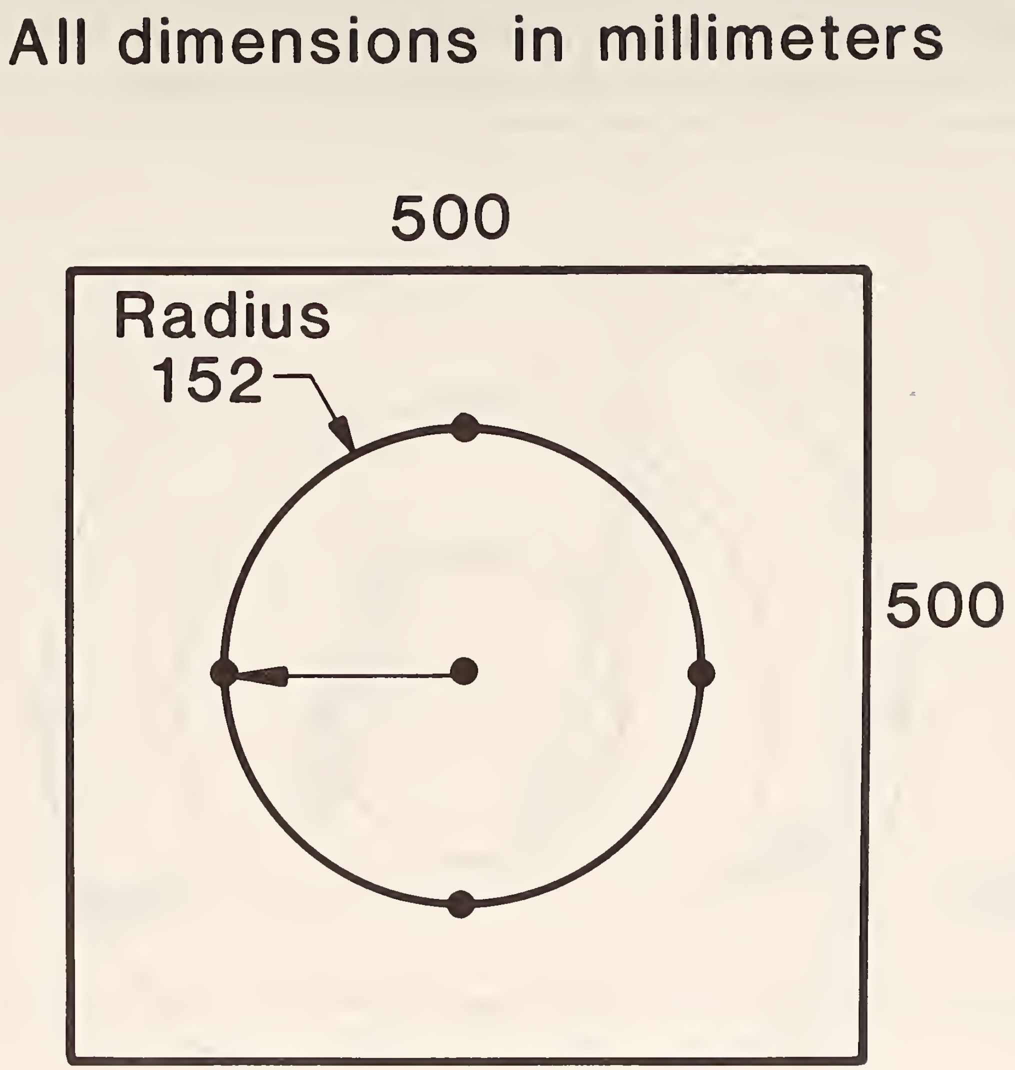


Figure 2. Thermocouple Placement on Appliance Surface

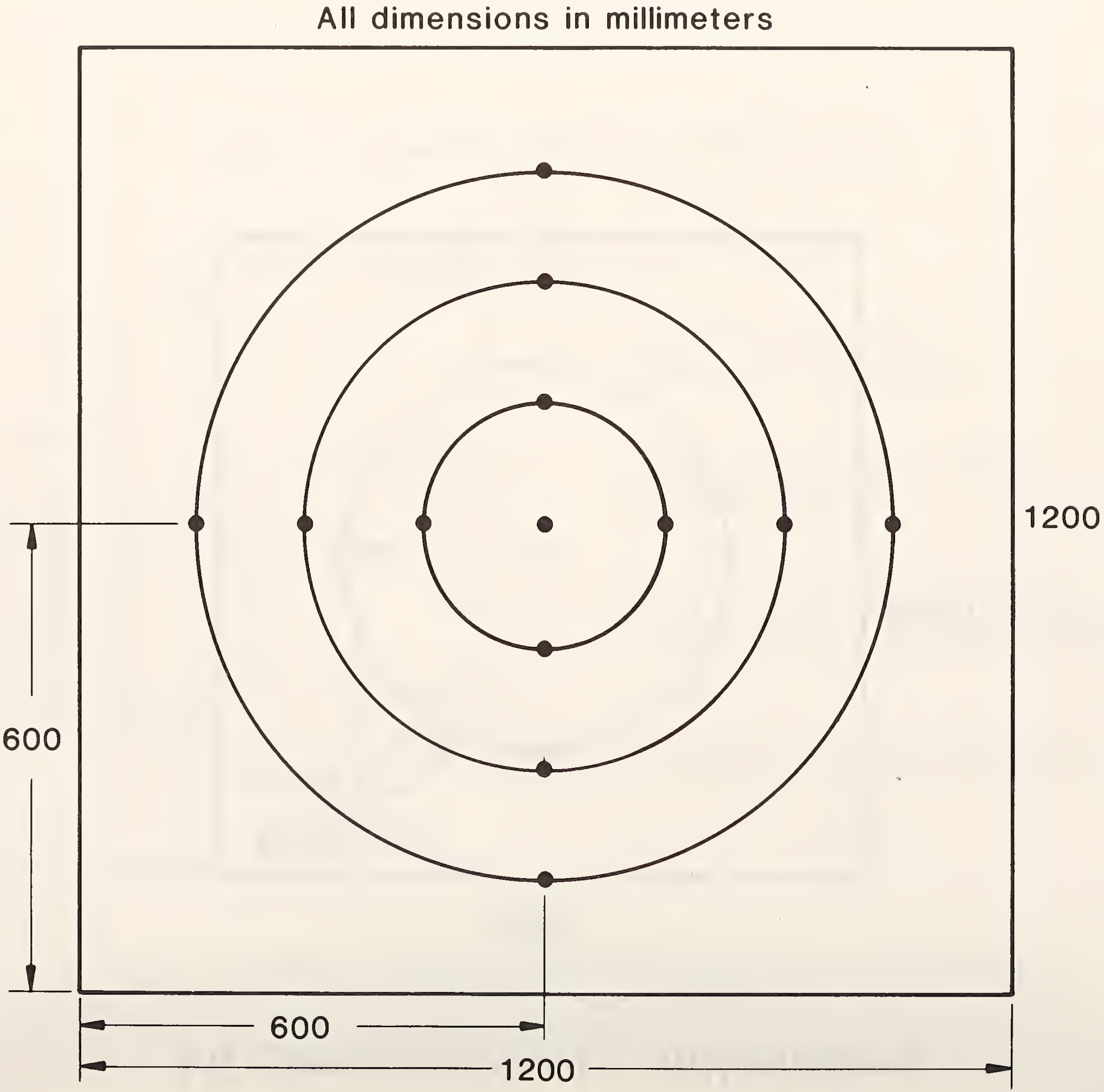


Figure 3. Thermocouple Placement on Protector and Wallboard Surface

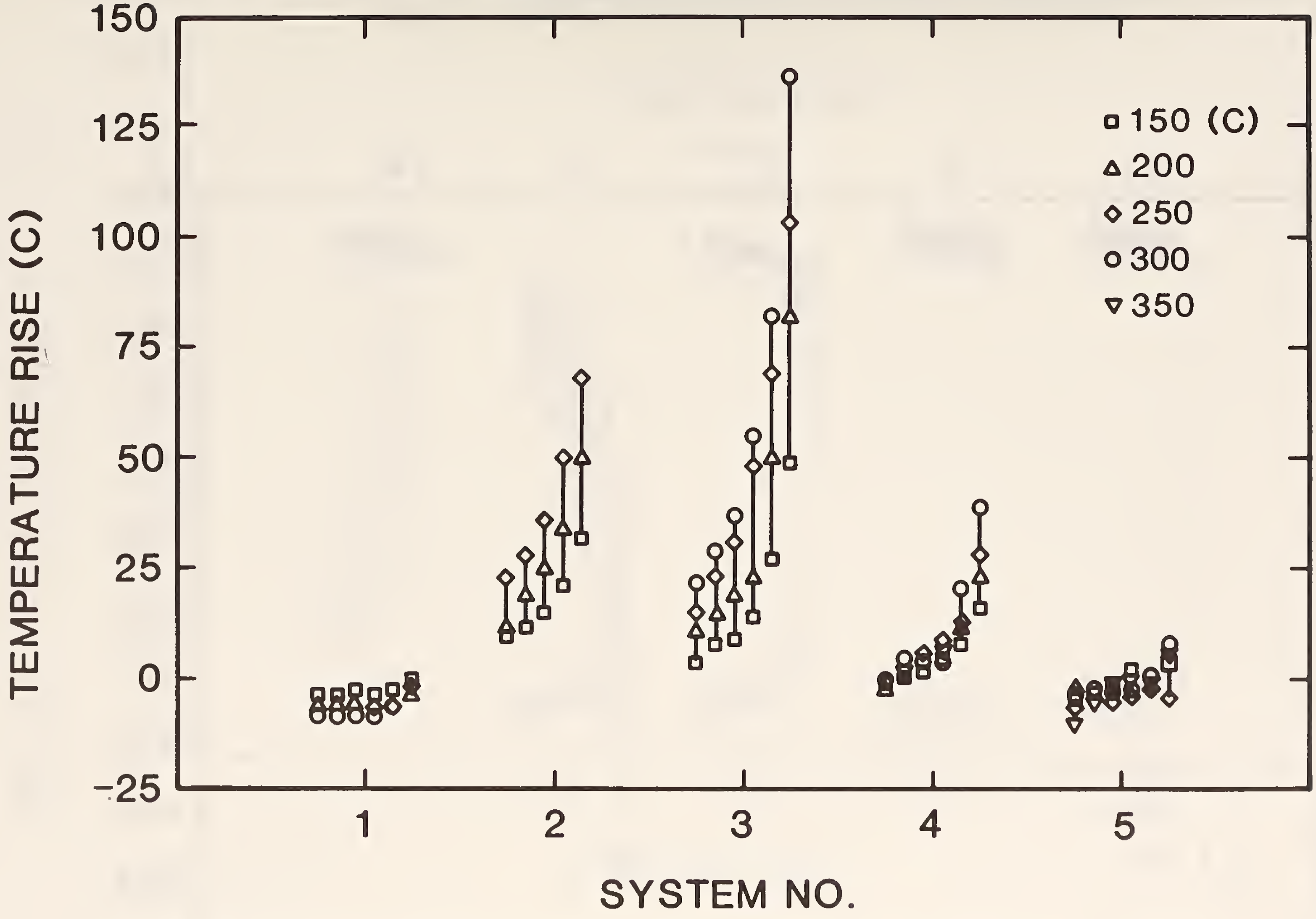


Figure 4. Temperature Rise on Gypsum Wallboard Surfaces (Unprotected-Protected) Exposed to Temperatures of 150, 200, 250, 300 and 350°C, Systems 1-5

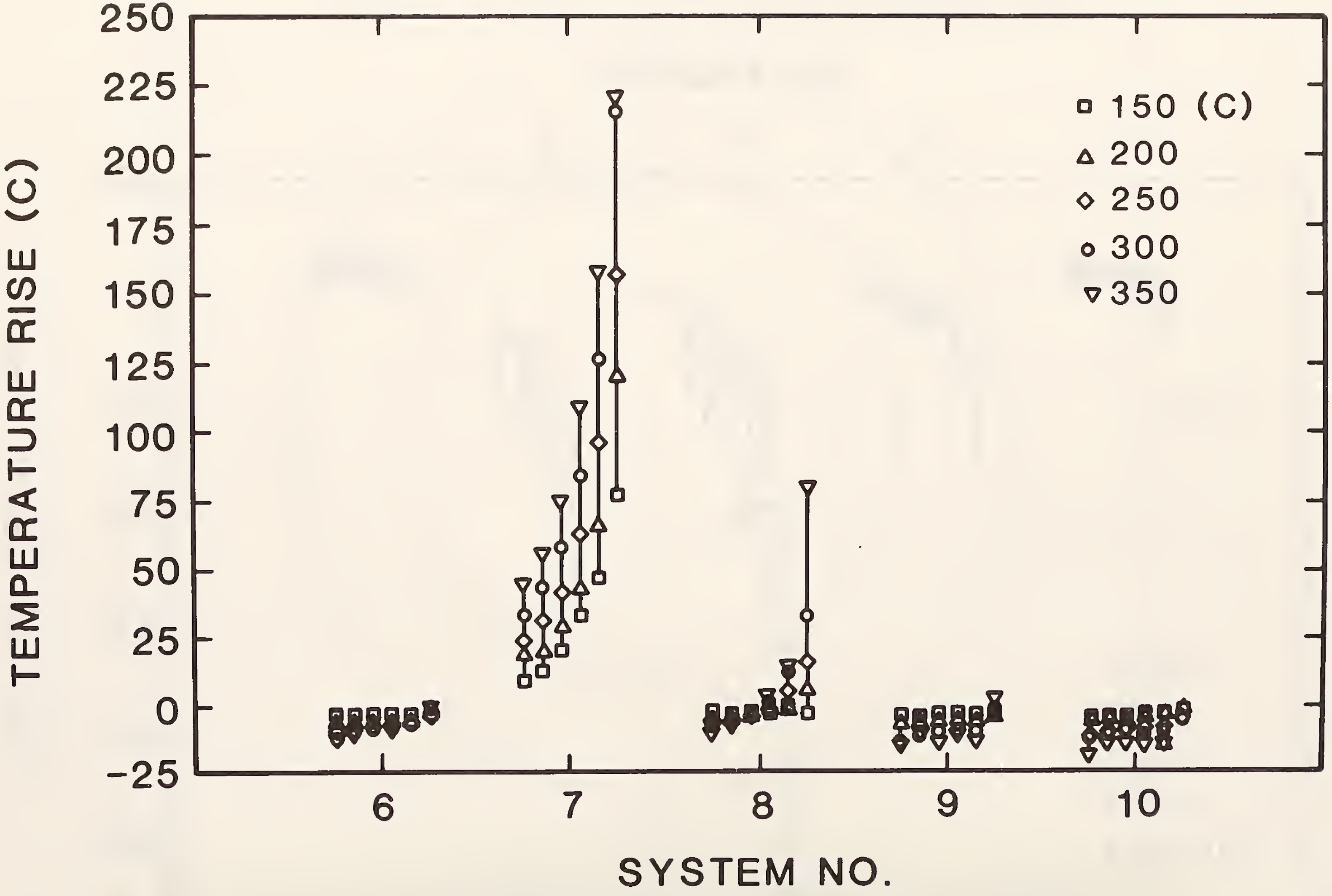


Figure 5. Temperature Rise on Gypsum Wallboard Surfaces (Unprotected-Protected) Exposed to Temperatures of 150, 200, 250, 300 and 350°C, Systems 6-10

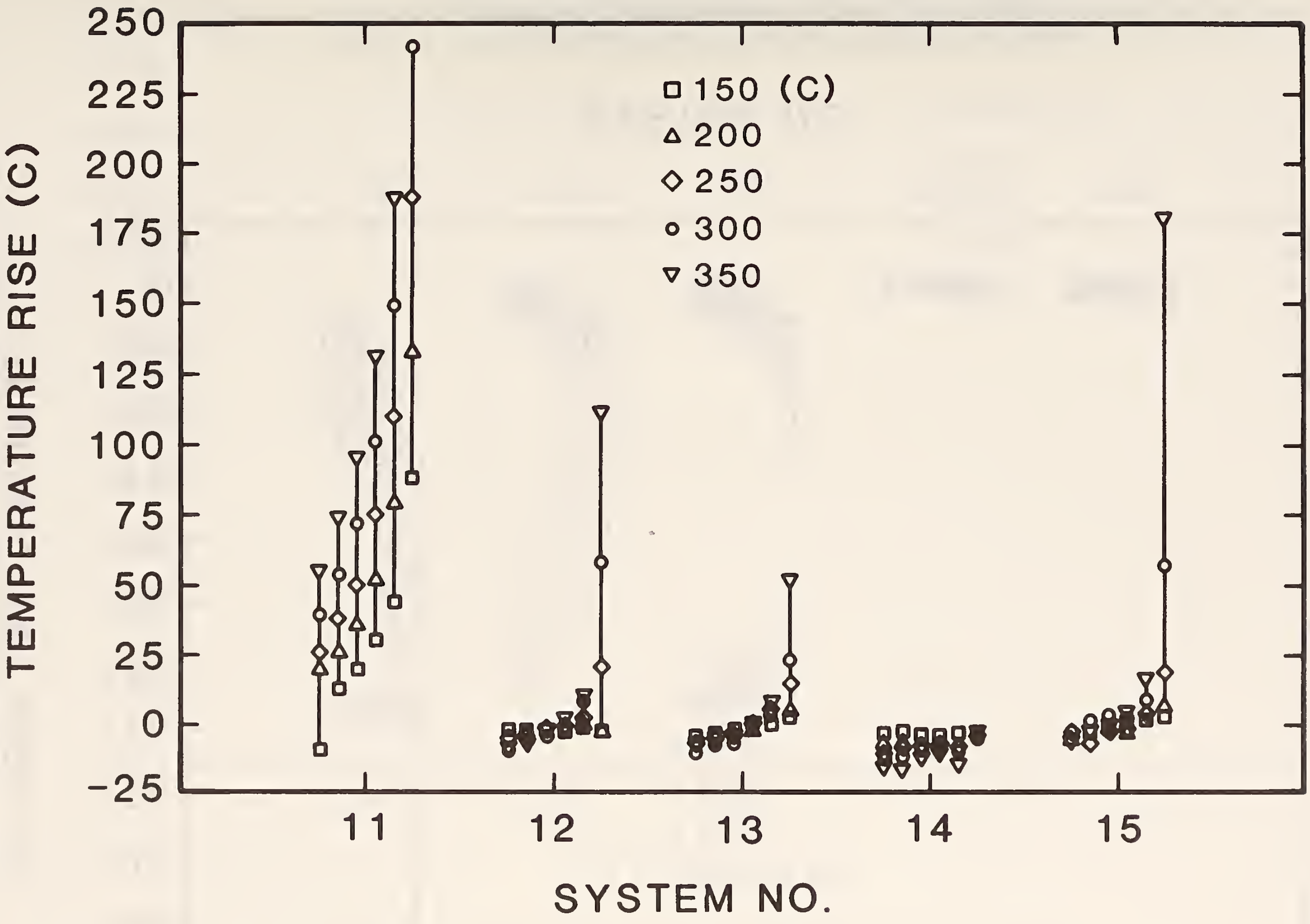


Figure 6. Temperature Rise on Gypsum Wallboard Surfaces (Unprotected-Protected) Exposed to Temperatures of 150, 200, 250, 300 and 350°C, Systems 11-15

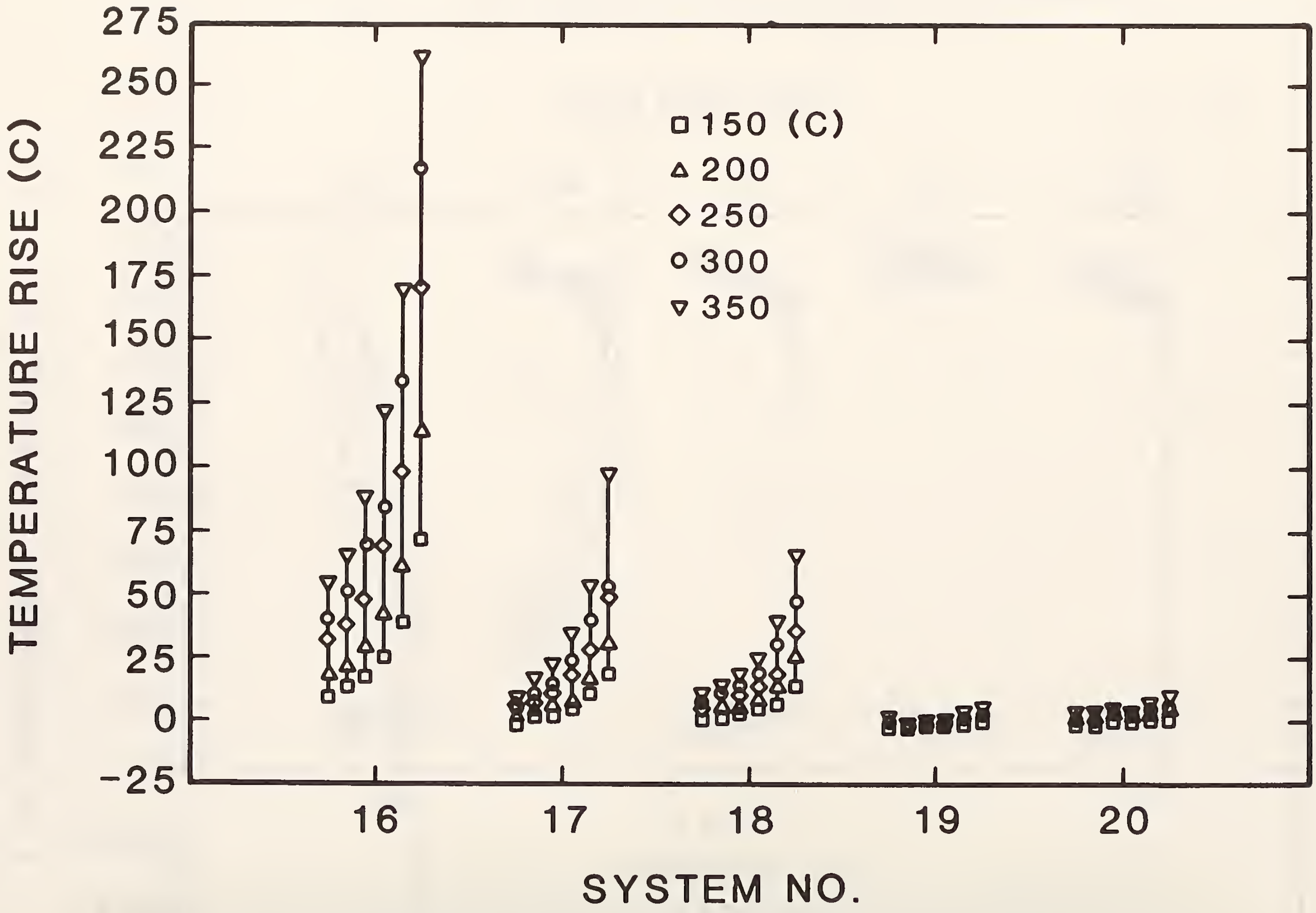


Figure 7. Temperature Rise on Gypsum Wallboard Surfaces (Unprotected-Protected) Exposed to Temperatures of 150, 200, 250, 300 and 350°C, Systems 16-20

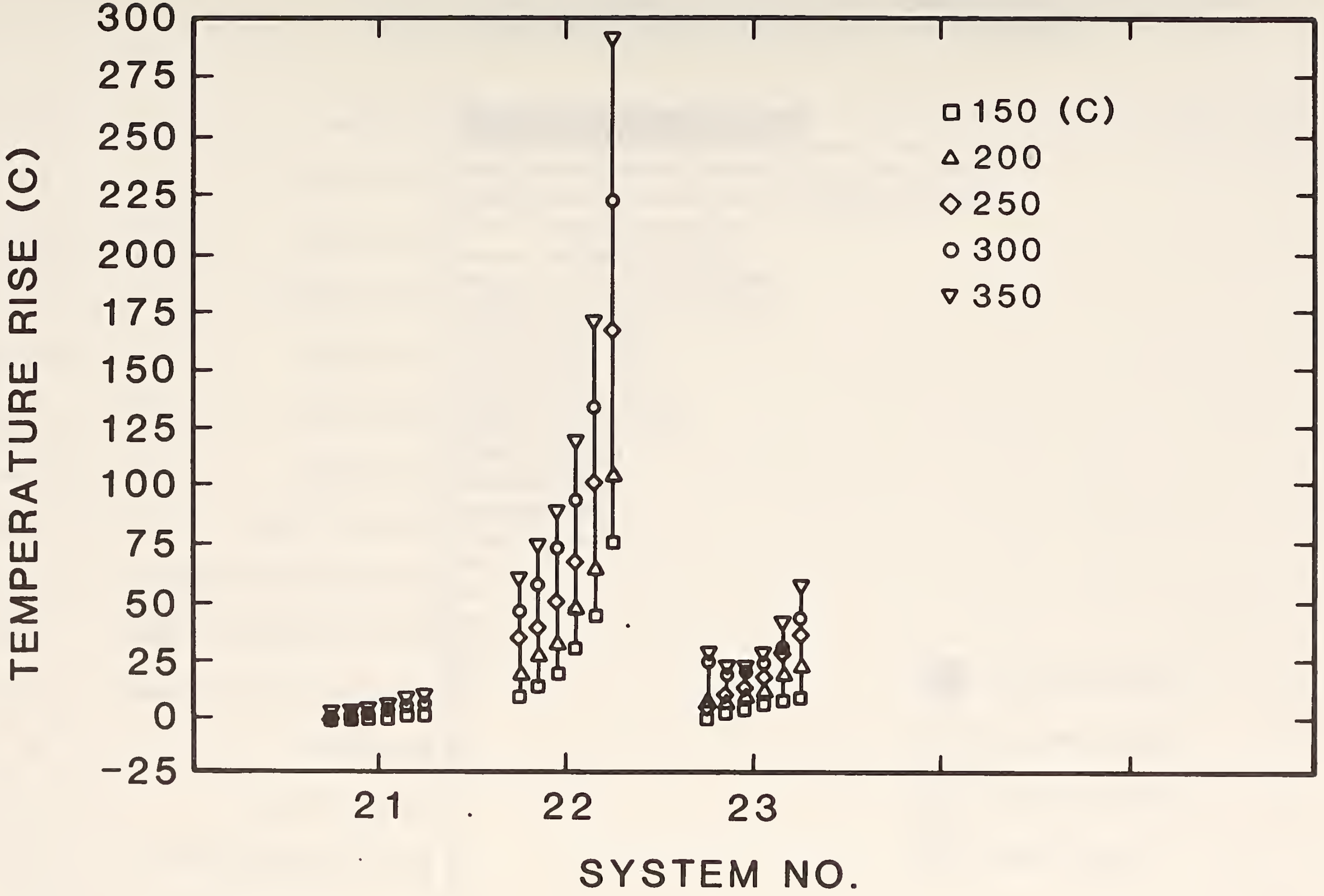


Figure 8. Temperature Rise on Gypsum Wallboard Surfaces (Unprotected-Protected) Exposed to Temperatures of 150, 200, 250, 300 and 350°C, Systems 21-23

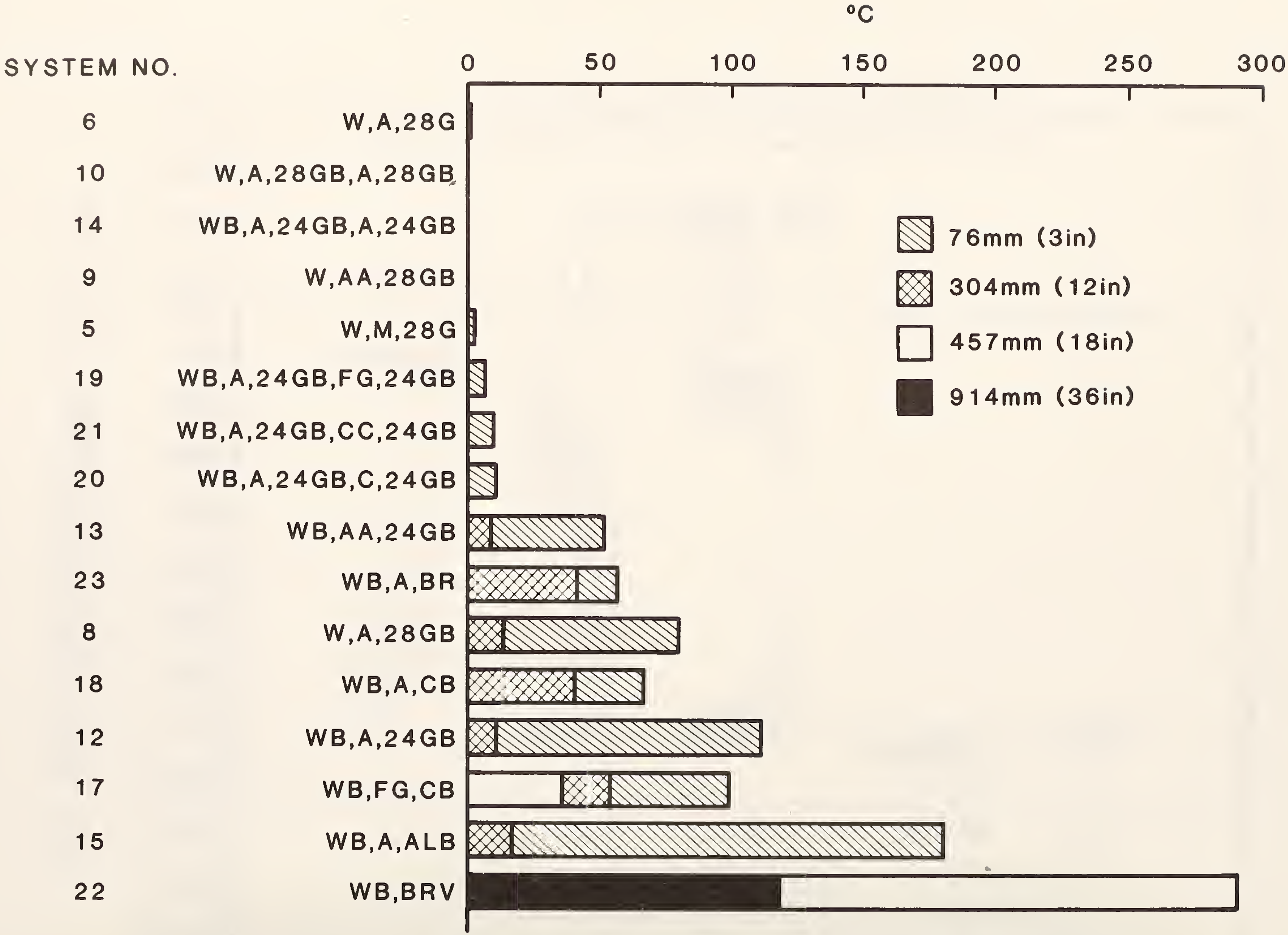


Figure 9. Surface Temperature Rise and Clearances for (Protected) Gypsum Wallboard Exposed to 350°C Stove Temperature

Part II. Systems for Protecting Wall and Ceiling Surfaces Exposed to Heating Appliance Chimney Connectors

11. TEST APPARATUS FOR CHIMNEY CONNECTOR TESTS

The test apparatus used for the Part II testing program consisted of the same stove apparatus as used in Part I (see Figure 1) plus a chimney connector pipe venting system. The connector pipe was conventional steel, single wall, 0.46 mm (0.018 in) thick and had a diameter measuring 152 mm (6 in).

Figure 10 shows a sketch of the stove and the location of vertical and horizontal chimney connector pipes in relation to the wall and ceiling panels. The vertical pipe measured 1.6 m (64 in) in length and had five 24 gauge (chromel-alumel) thermocouples attached to its outer surface in a vertical line central to the pipe. The first (or bottom) thermocouple was located 914 mm (36 in) from the floor and the other thermocouples were spaced 200 mm (8 in) apart. The thermocouples were attached to the steel pipe by metal washers fastened to the pipe with sheet metal screws. Attachments were made on the side of the pipe away from the wall for ease of maintenance.

Figure 11 shows a room wall section with 30 thermocouples attached to its front surface. Using thermocouple attachment procedures outlined in section 9.11 of UL 1482 "Room Heaters, Solid Fuel Type" the thermocouples were secured to the surface by staples placed over the insulated portion of the wires. The thermocouple tips were depressed flush to the wall surface at the point of measurement and held in thermal contact with the surface at that point by pressure sensitive electrical tape. The thermocouples, arranged 10 to a row, were spaced 152 mm (6 in) apart in vertical lines with the first or bottom thermocouple in each of the three rows located 914 mm (36 in) from the floor. Each row of thermocouples was connected in parallel, thus average temperatures were obtained.

Figure 12 shows a ceiling section with 9 thermocouples attached to the exposed (unprotected or protected) surfaces. Attachments were made in the same manner as described above. Spacing between thermocouples was 152 mm (6 in). This thermocouple string was connected in parallel also to obtain average temperatures.

12. TESTING PROGRAM

12.1 Test Systems

For the purposes of brevity, a key following table 3 identifies abbreviations for the various components used in the construction of the wall and ceiling systems. As indicated, gypsum wallboard served as the base material for each of the panels. This 16 mm (5/8 in) thick material was chosen because of its widely accepted use in room wall and ceiling construction found in dwellings. For a number of systems, the wallboard surfaces were painted black so that the effectiveness of different wall and ceiling protectors might be judged by their ability to reflect or absorb radiation and/or dissipate absorbed radiation.

The overall dimensions of the wall panels and their protective shields measured 1.2 x 2.4 m ((4 x 8 ft) and ceiling panels and shields measured 1.2 x 1.2 m (4 x 4 ft). The protector plate used for the ceiling panels was 0.61 mm thick (24 gauge) and was offset from the ceiling panel by a 25 mm (1 in) air space. In nine of the systems, the leading edge of the ceiling protector plate was located 25 mm (1 in) away from the vertical wall protector plate. This arrangement allowed for air circulation around the ceiling protector plate.

For three other systems, no separation existed between the wall and ceiling protector plates because the leading edge of the ceiling plate contacted or intersected the wall plate. (See systems 48, 49, and 50 in table 3). This arrangement permitted a study of the effect that "no air movement" between the wall and ceiling might have on surface temperatures of the protected wall and ceiling panels.

Table 3 details clearances between the wall and ceiling panels and the chimney connector pipe. For example:

- Clearances to ceilings ranged from 76 to 457 mm (3 to 18 in).
- Clearances to walls remained at 76 mm (3 in) for all tests.

Chimney connector exposure temperatures were 350, 400, and 450°C (662, 752, and 842°F).

12.2 Test Criteria

U.L. Standard for Room Heaters, Solid Fuel Type was used as the source of the test criteria [24]:

1. A surface temperature rise of 50°C (90°F) above room temperature is allowed for protected surfaces.
2. A surface temperature rise of 65°C (117°F) above room temperature is allowed for unprotected surfaces.

13. TEST RESULTS

Ceiling and wall panels were exposed to radiant energy from the chimney connector pipe until peak temperatures were recorded on their surfaces. Table 4 lists the clearances to wall and ceiling and the surface temperature rise (peak minus room temperature) for tests on each if the systems at the three different exposure temperature levels. Application of the test criteria to these data provided the pass-fail results listed in the following table.

13.1 Unprotected Ceiling Panel Tests

Clearance (mm/in)	System	Wall	Ceiling	Connector Surface Temperature @350°C	 @400°C	 @450°C
241/9.5	No. 25	WB, A, 24GB	WB	P	Fc	Fwc
241/9.5	No. 28	WB, A, 24GB, CC, 24GB	WB	P	P	Fc
241/9.5	No. 29	WB, A, 24GB, C, 24GB	WB	P	P	Fc
460/18	No. 30	WB, A, 24GB, C, 24GB	WB	P	P	P
460/18	No. 31	WB, A, T	WB	P	P	P
460/18	No. 37	W, P, A, 24G	WB	P	P	P
460/18	No. 38	W, P, A, 24GB	WB	P	P	Fw

Note: P = Pass, Fw = Fail wall only, Fc = Fail ceiling only, Fwc = Fail wall and ceiling

Results for the 241 mm (9.5 in) clearance tests show that the black painted unprotected ceilings and all wall panels passed 350°C (662°F) exposure tests. One ceiling failure was recorded for the 400°C (752°F) exposure - no. 25 (72°C). All ceilings and one wall failed the 450°C (840°F) exposure tests - no. 25 (83°C [181°F] on ceiling and 51°C [124°F] on wall), no. 28 (71°C-160°F) and no. 24 (73°C-163°F).

Results for 457 mm (18 in) clearance tests show that the ceiling panels passed all three exposure temperature tests and that one wall system failed the 450°C test - no. 38 (55°C).

13.2 Protected Ceiling Panels - with air circulation around the black painted ceiling protector plate

Clearance (mm/in)	System	Wall	Ceiling	Connector Surface Temperature @350°C	@400°C	@450°C
76/3	No. 39	WB, P, A, 24GB	WW, A, 24GB	P	P	Fwc
152/6	No. 40	WB, P, A, 24GB	WW, A, 24GB	P	P	P
229/9	No. 41	WB, P, A, 24GB	WW, A, 24GB	P	P	P

Note: P = Pass, Fwc = Fail wall and ceiling

As indicated above, the only failing test results were recorded for 76 mm (3 in)/450°C (842°F) exposure test of no. 39 where the protected wall surface reached 52°C and the protected ceiling panel 57°C.

13.3 Protected Ceiling Panels - with air circulation around an unpainted ceiling protector plate

Clearance (mm/in)	System	Wall	Ceiling	Connector Surface Temperature @350°C	@400°C	@450°C
229/9	No. 42	WB, P, A, 24GB	WW, A, 24G	P	P	P
152/6	No. 43	WB, P, A, 24GB	WW, A, 24G	P	P	P
76/3	No. 44	WB, P, A, 24GB	WW, A, 24G	P	P	P

Note: P = Pass

The only difference between the ceiling/wall systems listed above and the systems described in section 13.2 above was a coat of black paint on the ceiling protector plate. As indicated, the unpainted ceiling systems passed all clearance/exposure tests at all levels.

13.4 Protected Ceiling Panels - with air circulation around a white painted ceiling protector plate

Clearance (mm/in)	System	Wall	Ceiling	Connector Surface Temperature @350°C	@400°C	@450°C
229/9	No. 45	WB, P, A, 24GB	WW, A, 24GW	P	P	P
152/6	No. 46	WB, P, A, 24GB	WW, A, 24GW	P	P	P
76/3	No. 47	WB, P, A, 24GB	WW, A, 24GW	P	P	Fc

Note: P = Pass, Fc = Fail ceiling only

The only difference between the above ceiling/wall system and those discussed in sections 13.2 and 13.3 was a coat of white paint on the ceiling protector plate. A ceiling failure was recorded for no. 47 (55°C) at the 76 mm (3 in)/450°C (842°F) exposure.

13.5 Protected Ceiling Panels - with no air circulation around the white painted ceiling protector plate

Clearance (mm/in)	System	Wall	Ceiling	Connector Surface Temperature @350°C	@400°C	@450°C
229/9	No. 48	WB, P, A, 24GB	WW, A, 24GW	P	P	Fw
152/6	No. 49	WB, P, A, 24GB	WW, A, 24GW	P	P	Fwc
76/3	No. 50	WB, P, A, 24GB	WW, A, 24GW	P	Fc	Fwc

Note: P = Pass, Fw = Fail wall only, Fc = Fail ceiling only, Fwc = Fail wall and ceiling

The only difference between these systems and those described in section 13.3 is that the air gap separating the ceiling and vertical protector plates was eliminated. Lack of a means for air circulation around the ceiling protector plate showed that system no. 50 produced a ceiling failure (54°C-129°F) at 76 mm (3 in) clearance and 400°C (752°F) exposure and for the wall and ceiling (51 and 64°C, [124 and 147°F] respectively) at the 450°C (842°F) exposure. The wall in system no. 48 also failed at 450°C-842°F (51°C-124°F) as did the system no. 49 wall (53°C) and ceiling (53°C-127°F).

14. SUMMARY OF RESULTS

Figures 13 and 14 show plots of all the surface temperature rise data listed in table 4 for each exposure temperature and clearance test on ceiling panels. As expected, the highest values were recorded for unprotected ceilings and for panels closest to the chimney connector pipes.

A summation of the numbers of failures observed for each of the five test grouping shows the following:

Number of Failures During Chimney Connector/Wall Protection Tests

		Stove Temperature					
		350°C		400°C		450°C	
	Wall Protection System Type	Wall	Ceiling	Wall	Ceiling	Wall	Ceiling
I.	Unprotected Ceiling @241 mm	0	0	0	1	1^a	3
	Unprotected Ceiling @457 mm	0	0	0	0	1^a	0
II.	Black Plate - Air Cir.	0	0	0	0	1^a	1^a
III.	Unpainted Plate - Air Cir.	0	0	0	0	0	0
IV.	White Plate - Air Cir.	0	0	0	0	0	1^a
V.	White Plate - No Air	0	0	0	1^a	3^b	2^c

Total Failures: Wall 6 Ceiling 9

Note: a = 76 mm failures b = 76, 152, 229 mm failures c = 76 and 152 mm failures

15. TEST OBSERVATIONS

Based on an analysis of test results, the following observations are made:

(1) The NFPA code recommends 457 mm (18 in) clearance between single wall metal chimney connector pipes and ceilings. The results of CFR tests on unprotected (black painted) ceiling panels support this recommendation. Panels were exposed to three different temperature levels - 350, 400, and 450°C (662,752, and 842°F).

(2) At a clearance reduced to 241 mm (9.5 in), unprotected ceiling panels met code requirements for 350°C (normal operating temperature) exposure, but failures were recorded for the panels when subjected to overfire exposures of 400 and 450°C (752-842°F).

(3) Protected ceilings - Ceilings protected by an unpainted metal plate (plus air space) system passed all exposure temperature tests at 76 mm (3 in) clearances.

(4) Protected ceilings - Ceilings protected by white painted and black painted metal plate (plus air space) systems showed that clearances could be reduced to 76 mm (3 in) for 350 and 400°C (662 and 752°F) exposures, but only to 152 mm (6 in) for 450°C (842°F).

(5) The effect of no air circulation around the ceiling protector plate on surface temperature rise of ceiling and protected wall panels was clearly demonstrated in comparison tests of a protected ceiling panel/wall system - (protector white painted metal plate plus air space). For all exposure tests, the air circulating system showed a single failure (76 mm-3 in/450°C-752°F); however, for "no air" tests, the total was six failures, one at 76 mm (3 in)/400°C (752°F), and five at the 450°C (842°F) exposure - walls at 76, 152, and 229 mm (3, 6 and 9 in) clearance and ceilings at 76 and 152 mm (3 and 6 in) clearance.

(6) Protected walls gave satisfactory results for 76 mm (3 in) clearances to vertical chimney connector pipes for 350 and 400°C (662 and 752°F) exposures; however, the walls showed failures at the 450°C (842°F) exposure.

16. CONCLUSIONS

The following conclusions apply to those testing conditions when a 152 mm (6 in) diameter single wall metal pipe connector was used to expose protected walls and protected and unprotected ceilings to temperatures of 350, 400, and 450°C (662, 752, and 842°F).

(1) Clearances between horizontal chimney connector pipes and unprotected ceiling panels should be 457 mm (18 in).

(2) Clearances between protected ceiling panels and chimney connector pipes should be at least 152 mm (6 in).

(3) Clearances between vertical chimney connector pipes and protected walls should be at least 152 mm (6 in).

(4) If protected walls are combined with no air circulation protected ceiling systems, the clearance to the vertical pipe should be 304 mm (12 in) or greater.

(5) If protected ceiling panels have no provision for air circulation the clearance to the connector pipe should be 304 mm (12 in) or greater.

(6) Although an unpainted metal protector plate system exhibited acceptable clearance reductions to 76 mm (3 in) between ceilings and chimney connector pipes, protector systems painted white or black were not acceptable at all clearances. It, therefore, appears desirable that a minimum 152 mm (6 in) clearance be used for all ceiling metal plate protectors with air space.

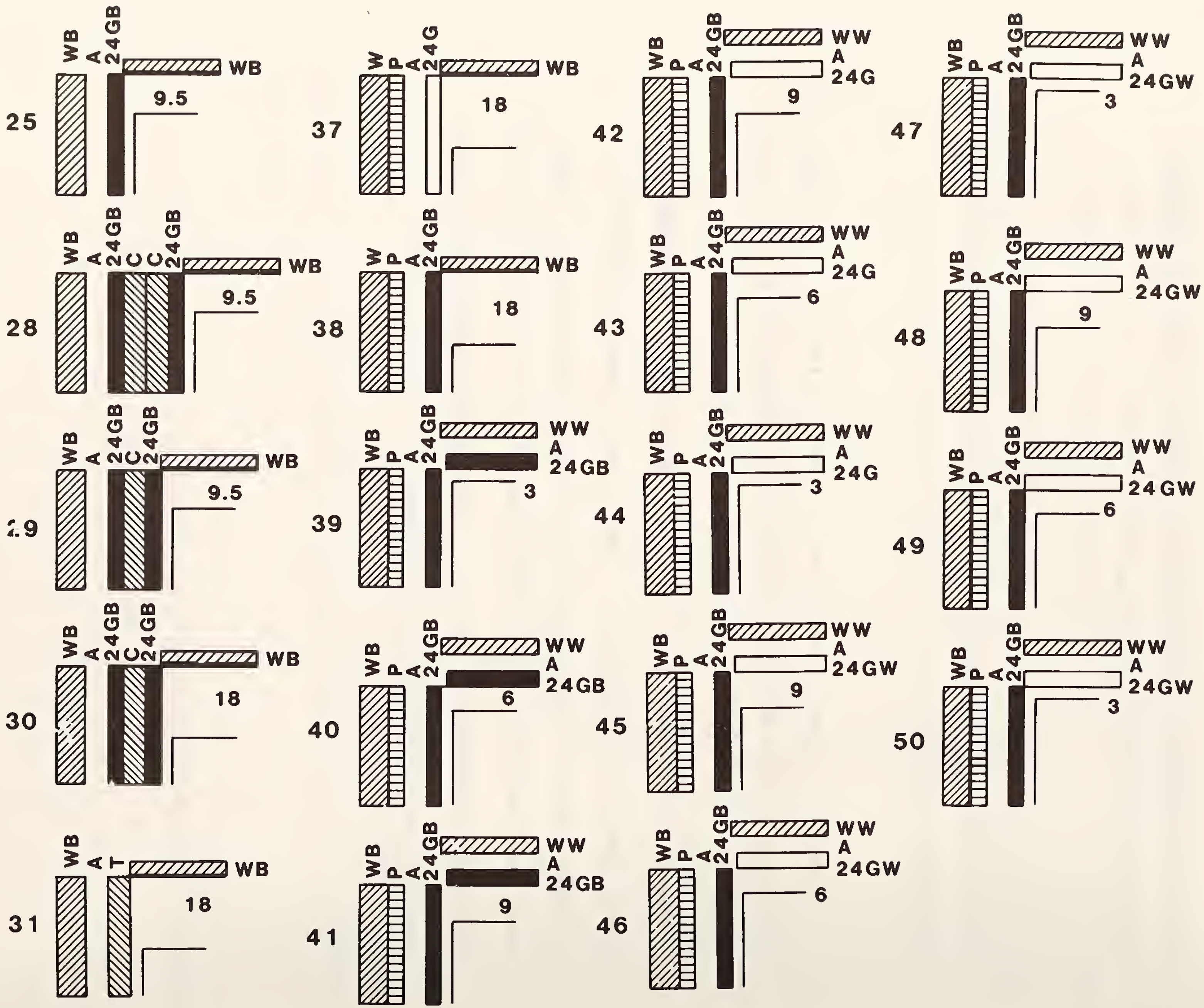


Table 3. Nineteen Wall-Ceiling Systems Tested

KEY to Table 3

Components Used For Wall and Ceiling Systems

Identification	Material	Thickness (mm)	 (in)
W	Gypsum Wallboard Surface Unpainted	10	0.38
WW	Gypsum Wallboard Surface Painted White	10	0.38
WB	Gypsum Wallboard Surface Painted Black	10	0.38
A	Air Space	25	1.00
C	Inorganic Insulation Board "C"	6	0.25
CC	Inorganic Insulation Board "C"	12	0.50
CB	Inorganic Insulation Board "C" Painted Black	6	0.25
24G	Galvanized Metal Plate Unpainted	0.6	0.024
24GW	Galvanized Metal Plate Painted White	0.6	0.024
24GB	Galvanized Metal Plate Painted Black	0.6	0.024
P	Wood Paneling	18.8	0.75
T	Wall Mat (Plaster Type)	25	1.0

Table 4. Wallboard Surface Temperature Rise Measured During Tests of Chimney Connector/Wall Protection Systems

	Clearance to:		Stove Temperature 350°C		400°C		450°C	
Test #	Wall (mm/in)	Ceiling (mm/in)	Wall (°C)	Ceiling (°C)	Wall (°C)	Ceiling (°C)	Wall (°C)	Ceiling (°C)
25	76/3	241/9.5	36	62	43	72[b]	51	83
28	76/3	241/9.5	25	54	29	64	32	71
29	76/3	241/9.5	28	53	33	60	38	73
30	76/3	457/18	15	38	19	39	20	46
31	76/3	457/18	24	33	27	38	33	43
37	76/3	457/18	0	37	4	45	4	50
38	76/3	457/18	29	38	40	46	55	41
39[a]	76/3	76/3	33	40	40	45	52	57
40[a]	76/3	152/6	30	35	40	42	49	48
41[a]	76/3	229/9	30	33	40	40	46	45
42[a]	76/3	229/9	27	25	35	31	44	45
43[a]	76/3	152/6	26	26	33	30	42	37
44[a]	76/3	76/3	25	34	35	33	43	37
45[a]	76/3	229/9	24	29	29	36	42	43
46[a]	76/3	152/6	29	36	39	42	49	48
47[a]	76/3	76/3	26	38	35	46	47	55
48[a]	76/3	229/9	27	31	37	38	51	46
49[a]	76/3	152/6	29	34	38	42	53	53
50[a]	76/3	76/3	29	48	41	54	51	64

Note: a = Protected Ceilings, b = Underlined data indicate failures

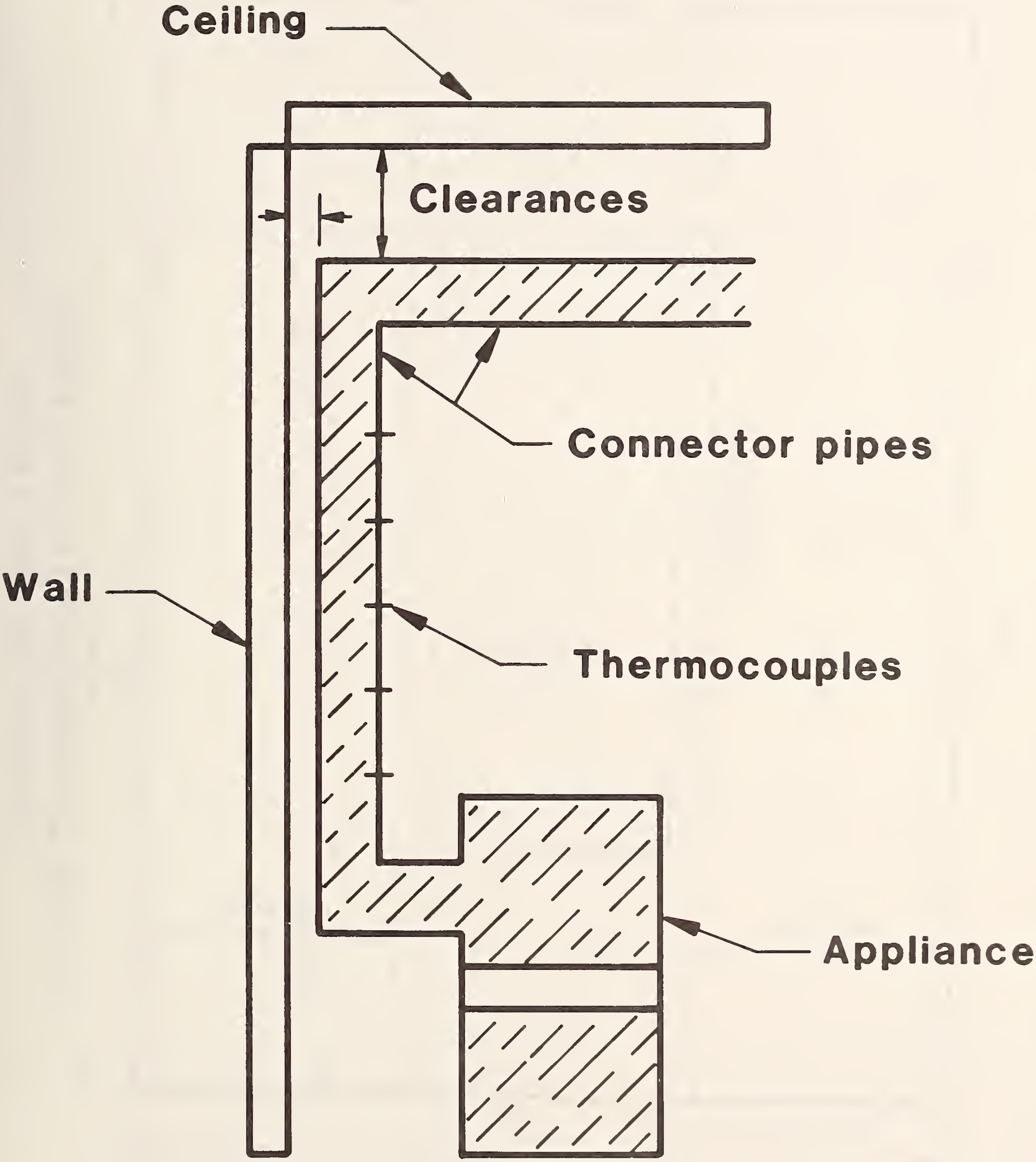


Figure 10. Relation of Stove and Ceiling Connector Pipe System to Wall and Ceiling Panels

CONNECTOR PIPE TESTS
VERTICAL WALL THERMOCOUPLE LOCATIONS

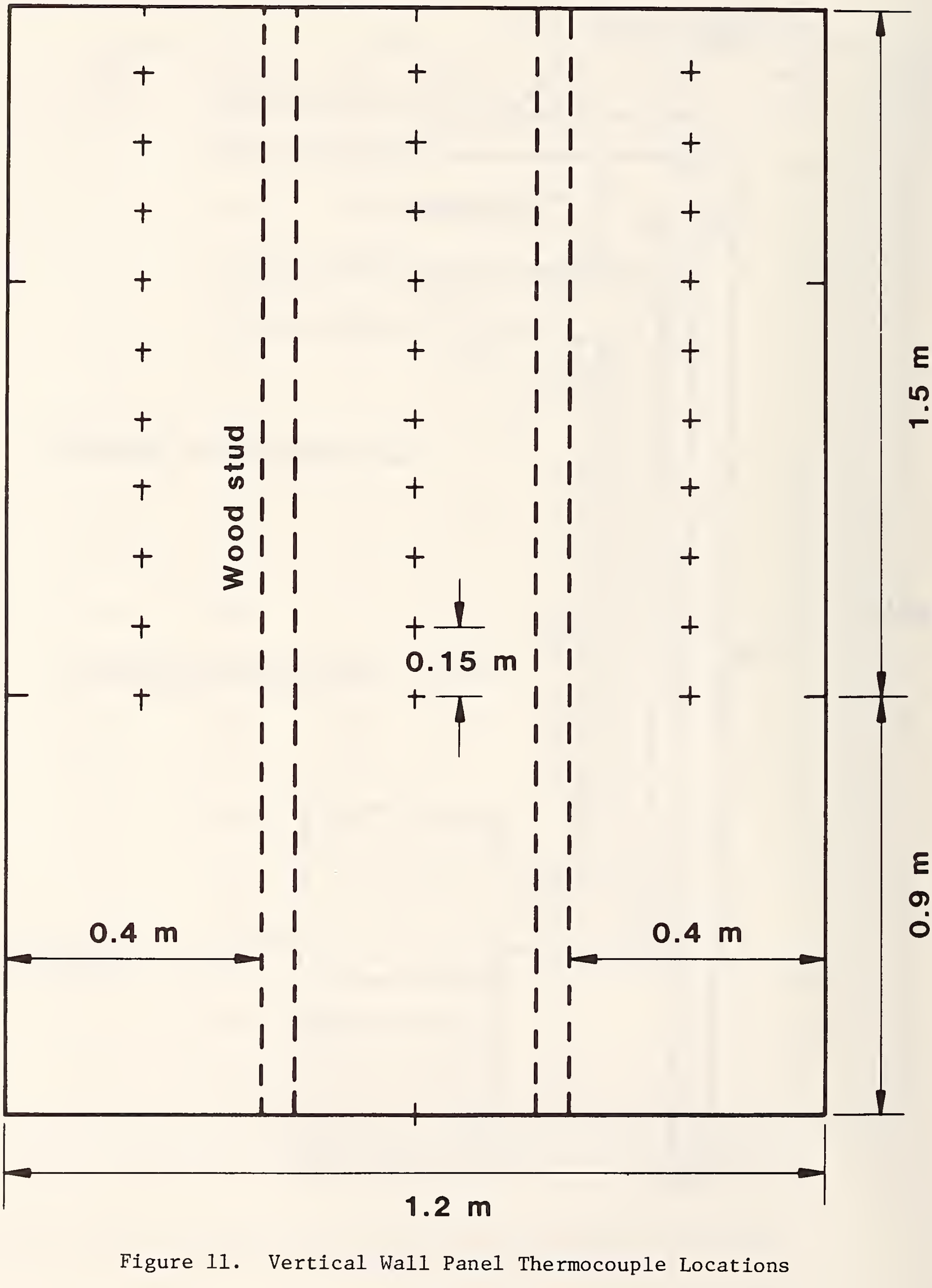
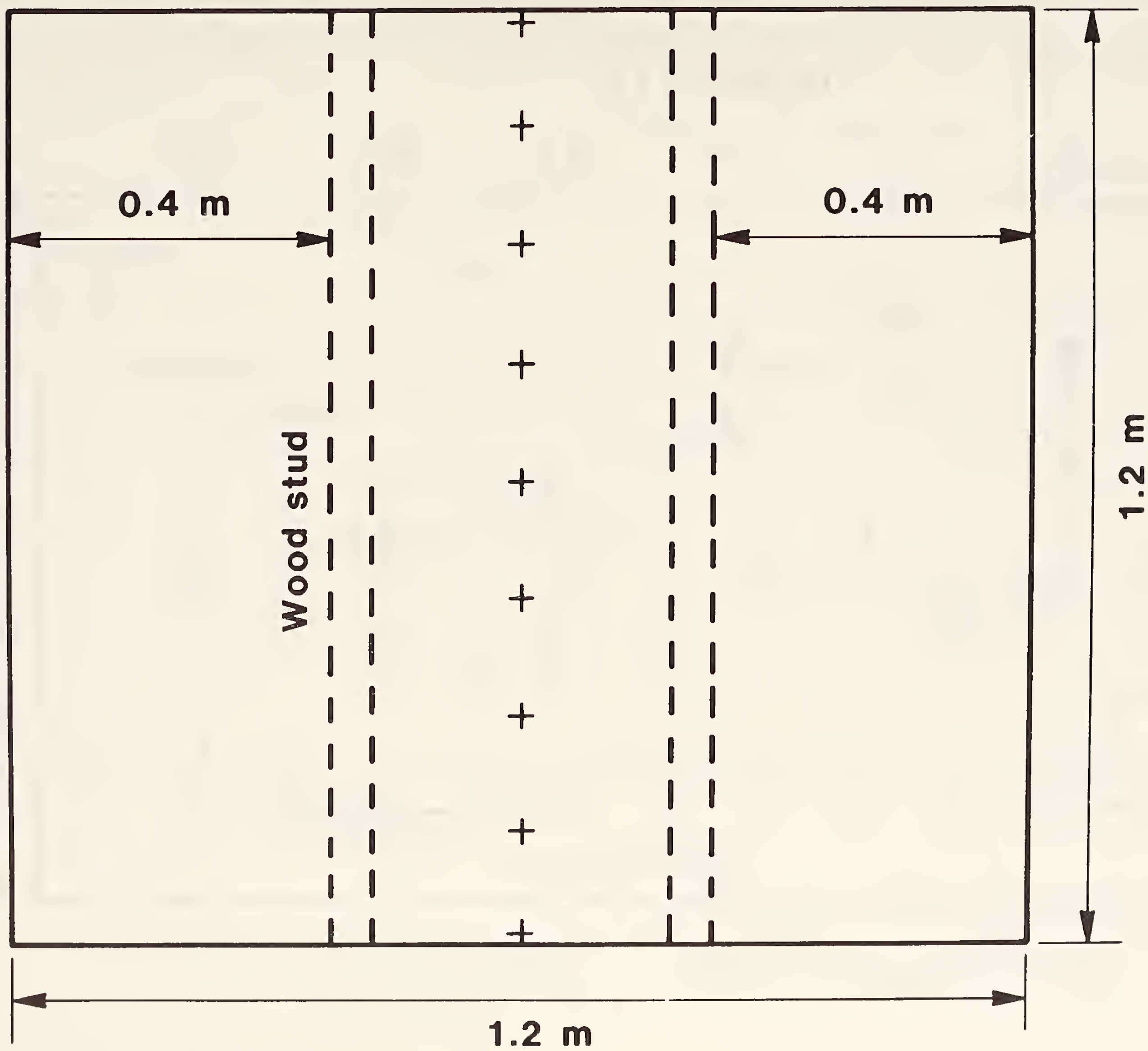


Figure 11. Vertical Wall Panel Thermocouple Locations



CONNECTOR PIPE TESTS
CEILING THERMOCOUPLE LOCATIONS

Figure 12. Ceiling Panel Thermocouple Locations

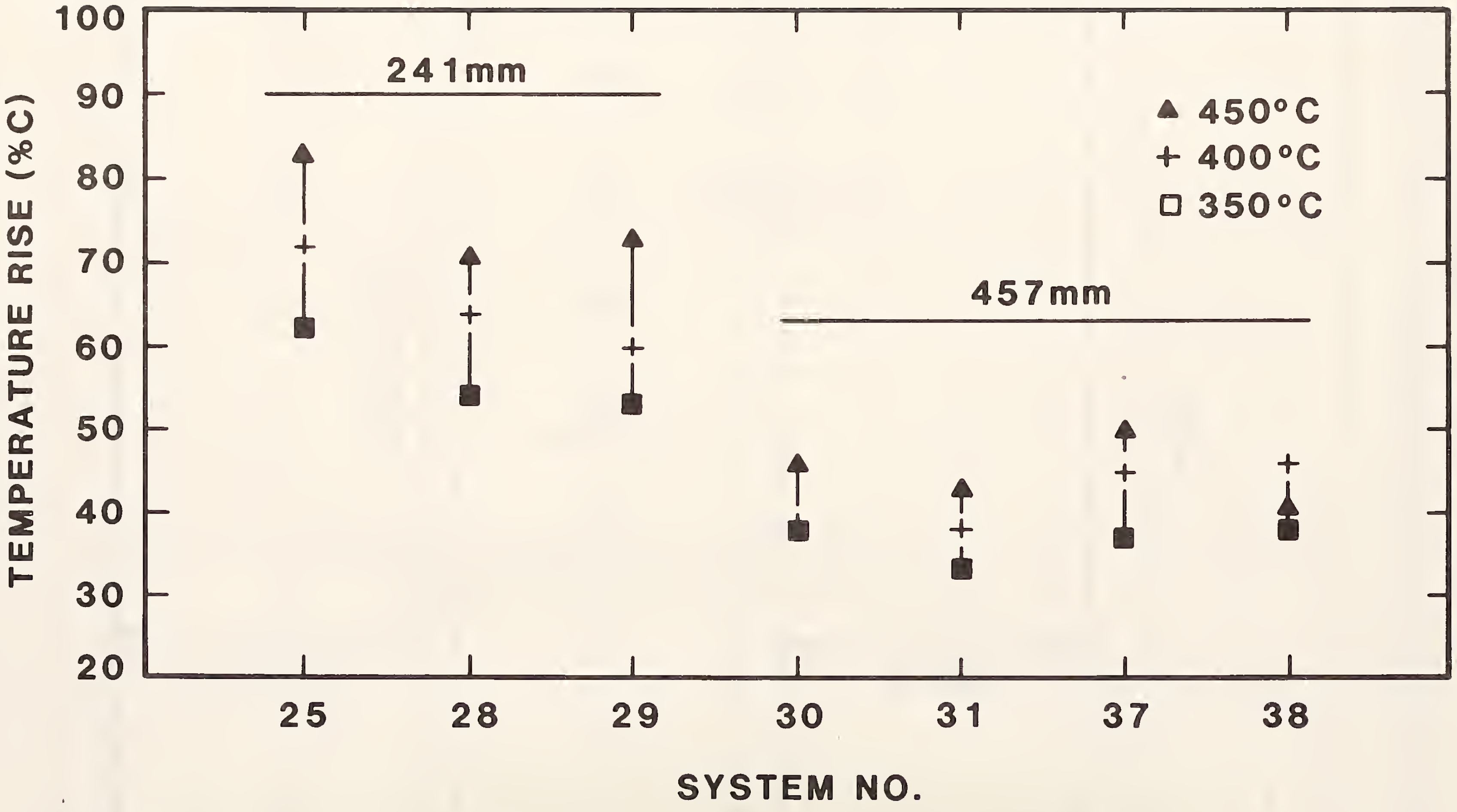


Figure 13. Temperature Rise on Ceilings for Exposure Temperature Levels of 350, 400 and 450°C and Clearances of 241 and 457 mm

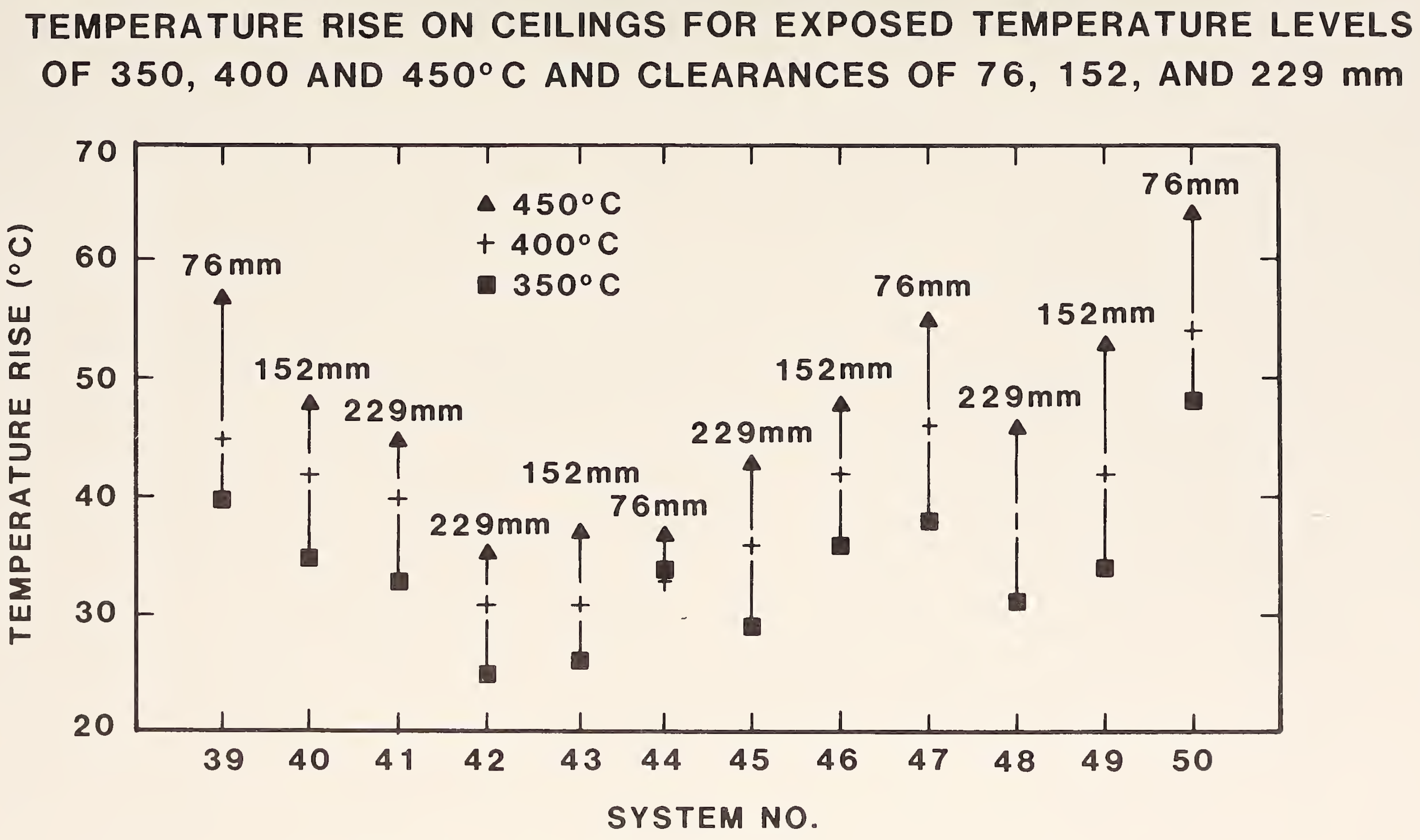


Figure 14. Temperature Rise on Ceilings for Exposure Temperature Levels of 350, 400 and 450°C and Clearances of 76, 152 and 229 mm

Part III: Full Room Validation of Wall and Ceiling Devices for Heating Appliance and Chimney Connector Systems

17. FULL ROOM VALIDATION TESTS

Based on results obtained for radiant energy exposure tests of mock-up wall panels shielded from hot appliance surfaces by various protection systems (Part 1) and an evaluation of protection devices for mock-up wall and ceiling panels exposed to chimney connector pipe systems (Part 2) a third series of tests was conducted to evaluate the thermal effects of heating appliance and chimney connector pipe combination systems in full room validation tests of walls and ceilings. A total of 14 different protection devices were evaluated in the study. Appliance and connector pipe exposure temperatures were 350, 400 and 450°C (662, 752 and 842°F). Temperature rise measurements were made on the surfaces of unprotected walls and ceilings and on walls shielded by various protection systems.

The full scale room ceiling provided satisfactory results for normal operational exposures (350°C) but showed a need for protective devices when exposed to temperatures generated by overfire test conditions of 400 and 450°C. Minimum clearances (between the appliance and full scale room wall surface) determinations were made to establish compliance with code recommended temperature rise limitations.

18. TEST ROOM DESCRIPTION

A full size room with approximate dimensions of 3.6 x 3.6 x 2.4 m (12 x 12 x 8 ft) high was constructed for these tests. Walls and ceilings were made of 5/8 in thick gypsum wallboard. Figure 15 shows the locations for the 24 gauge chromel-alumel thermocouples attached vertically and horizontally to the exposed wall surface and across the ceiling. Spacing between thermocouples was 152 mm (6 in) and the output for each thermocouple was read individually. Figure 16 shows the appliance with thermocouples attached to the vertical "exposure side" of the fire box. The output from these parallel connected thermocouples was used to monitor temperatures on the appliance surface. Figure 17 illustrates the relation of the appliance and chimney connector pipes to the test wall and ceiling. For these tests, the appliance was mounted on a sled fitted with casters to allow for movement to any desired clearance from the test wall. Figure 18 shows that portion of the wall surface shielded by a protector plate system. The protector extended 457 mm (18 in) beyond the sides and top edges of the appliance and 229 mm (9 in) to either side of the 152 mm (6 in) diameter chimney connector pipe.

19. TESTING PROGRAM

19.1 Test Systems

Table 5 shows sketches of the wall/ceiling test systems. The base gypsum wallboard wall and ceiling was unprotected and painted white for system R1 while for R2 the base material was painted black. System R3 consisted of a white painted wall protected by a 25 mm (1 in) air space and a black painted 28 gauge sheet metal plate. For all remaining test systems, the base wall and ceiling surface were painted black to maximize radiative absorption of energy. For system R4 the wall was protected by alternating air space and metal plates (24 gauge) painted black. R5 used an air space and sandwich panel consisting of fiberglass between 24 gauge sheet metal plates (black). Systems R6, R7 and R8 used a 13 m (1/2 in) thick insulation board (M), as the protector, for R6 the board was offset from the wall by a 25 mm (1 in) air space and was unpainted. R7 used the same setup but the board surface was painted black. R8 used fiberglass behind the board instead of an air gap. The wall for system R9 consisted of 13 mm (1/2 in) thick knotty pine paneling backed by extruded polystyrene foam insulation board. R10 used an air space and 24 gauge sheet metal plate (black) to protect the system used for R9. The protection used for R11 and R12 consisted of a 28 gauge sheet metal plate attached to a black painted insulation board. R11 used an air gap; R12 did not. System R13 used a protective package consisting of an air gap and insulation board sandwiched between 28 gauge plates painted black. R14 used a brick wall and a 51 mm (2 in) air separation to protect the test wall surface.

For the purposes of these tests the test systems were evaluated under the following conditions:

- Clearances to walls were varied from 76 mm to 1.07 m (3 to 42 in).
- Clearance to ceilings remained at 457 mm (18 in) for all tests.
- Appliance surface temperatures were 350, 400, and 450°C (662, 752, and 842°F).

19.2 Test Criteria

UL Standard for Room Heaters Solid Fuel Type UL 1482 First Edition [25], was used as the test criteria:

- A surface temperature rise of 50°C (90°F) above room temperature is allowed for protected surfaces.
- A surface temperature rise of 65°C (117°F) above room temperature is allowed for unprotected surfaces.

20. TEST RESULTS

20.1 Walls

Surface temperature rise, typical for exposure tests on room walls is shown in figures 19 and 20 for wood paneled wall R9. Table 6 lists all of the wall systems and the range of temperature rise on the surfaces of the walls along horizontal and vertical lines for tests at three different exposure temperature levels where clearances between appliance and walls were varied over a range from 1.07 m (42 in) to 76 mm (3 in). Plots of these data are shown in figures 21 to 28. Based on an analysis of these data plots, table 7 lists the minimum clearances found necessary between an appliance and room wall for three different test temperature levels in order to meet code specified surface temperature rise requirements or limitations.

20.2 Ceilings

A typical surface temperature rise on a test ceiling is shown in figure 29 for the wood paneled wall system R9. Figure 30 shows the range of temperature rise for all room ceilings under conditions where clearances to room walls were varied for tests at different exposure temperatures. Table 8 lists the wall/ceiling systems and identifies the clearances to walls at which the test ceiling registered a higher surface temperature than recommended (65°C-117°F) by the code.

21. TEST OBSERVATIONS

21.1 Room Walls

An examination of the minimum clearance data for walls listed in Table 7 shows that:

(1) Unprotected systems R1, R2 and R9 needed code recommended clearances of 914 mm (36 in) for 350°C (662°F) exposures. R1 (WW) also passed tests at 400°C (752°F) but the others did not. None passed at 450°C (842°F).

(2) A total of 7 systems, R3, R4, R5, R11, R12, R13 and R14 provided for clearance reductions to 76 mm (3 in) at the 350°C (662°F) exposure. Except for R12 all of the systems had an air space between the wallboard and protector and except for R14 (a brick wall) all had the benefit of metal plate(s) for the exposed surface. Systems with one metal plate were R3, R11, and R12. At exposures of 400°C System R12 showed a need for clearances greater than 305 mm (12 in) and R11 and R3 required 76 mm (3 in) and 152 mm (6 in) clearances respectively. At the 450°C (842°F) exposure all of the one plate systems needed clearances greater than 305 mm (12 in). Systems with two metal plates R4, R5 and R13 passed all of the

all of the exposure tests at 400 and 450°C (752 to 842°F). System R14 (brick wall) required 229 mm (9 in) clearance at 400°C (752°F) and 305 mm (12 in) clearance at 450°C (842°F).

(3) Three systems R6, R7 and R8 used a 12 mm (0.5 in) thick insulation board as a protector for the base wallboard. R6 and R7 had an air space between the protector and wallboard while R8 used fiberglass insulation. Systems R6 and R7 passed exposure tests at 350 and 400°C (662 and 752°F) at a clearance of 305 mm (12 in) but showed a need for clearances greater than 305 mm (12 in) at 450°C (842°F). System R8 passed the 350°C exposure test at the 305/mm (12 in) clearance but showed a need for clearances greater than 457 mm (18 in) at the 400 and 450°C (752 and 842°F) exposures.

21.2 Room Ceilings

For this test series, all 14 gypsum wallboard ceilings were unprotected and were located 457 mm (18 in) away from the horizontal chimney connector pipe. The ceiling in system R1 was painted white while all others were painted black.

(1) All test ceilings passed normal stove operational tests at 350°C (662°F). (Code limit is 65°C rise above room temperature.)

(2) Ceilings in 7 systems; R1, R2, R3, R4, R5, R7, and R8 met code temperature requirements for overfire exposures at 400 and 450°C (752 and 842°F).

(3) Ceilings in 7 systems; R6, R9, R10, R11, R12, R13, and R14 failed to meet code limits for the overfire conditions at 400 and 450°C (752 and 842°F).

(4) At the 400°C (752°F) exposure, the ceilings in systems R6, R10, R11, R12 and R13 passed tests when the stove and chimney connector were located 76 and 152 mm (3 and 6 in) away from the test wall however when the separation to the wall was 304 mm (12 in) the ceilings failed to meet code temperature requirements. Failing temperatures were borderline ranging from 1 to 4°C above the 65°C limit.

(5) For the 450°C (842°F) exposures the failing ceilings showed temperature rise values varying from 2 to 12°C above the code limit. Failures were recorded for 76 to 304 mm (3 to 12 in) clearances.

22. CONCLUSIONS

Based on an analysis of test results, the following conclusions are drawn:

(1) For normal stove operational conditions 350°C (662°F) unprotected room walls and ceilings showed code acceptable surface temperature rise when tested at code recommended clearances; i.e., 914 mm (36 in) between the stove surface and room wall and 457 mm (18 in) between the ceiling and horizontal chimney connector pipe.

(2) When the stove was operated at overfire conditions i.e., 400-450°C (752-842°F), clearances between unprotected room walls and the stove surface had to be increased significantly, i.e., beyond 914 mm (36 in).

(3) Thermal barriers, such as air space/metal plate and air space/insulation board were found effective in helping to reduce the effects of radiant energy from hot stove surfaces on adjacent room wall surfaces.

(4) Under normal operating conditions, 350°C (662°F), an air space/metal plate system allowed for clearance reductions to 76 mm (3 in), while an air space/insulation board system permitted reductions to 305 mm (12 in).

(5) Room ceilings were found to need protective barriers to accommodate overfire conditions such as a stove operating at 400 and 450°C (752 and 842°F).

23. RECOMMENDATIONS

From the tests on wall and ceiling protection systems (Parts I and II) and the full room verification of the systems (Part III), several systems that provide protection to combustible walls and ceilings were shown to be appropriate. Possible text for model building code specifications for wall and ceiling protection is detailed below.

1. Clearances from residential heating appliances to combustible material may be reduced if the combustible material is protected as described in table 9 and in figures 31 to 35.

2. For clearance reduction systems using an air space between the combustible wall and the wall protector, adequate air circulation shall be provided by one of the following methods as shown in figure 35:

   - Adequate air circulation may be provided by leaving all edges of the wall protector open with at least a 25 mm (1 in) air gap.

   - If the wall protector is mounted on a single, flat wall away from corners, adequate air circulation may be provided by leaving only the bottom and top edges or only the side and top edges open with at least a 25 mm (1 in) air gap.

   - Wall protectors that cover two walls in a corner shall be open at the bottom and top edges with at least a 25 mm (1 in) air gap.

3. All clearances shall be measured from the outer surface of the combustible material to the nearest point on the surface of the appliance, disregarding any intervening protection applied to the combustible material.

4. All clearances provided between residential heating appliances and combustible materials shall be large enough so as to maintain sufficient clearances between both the chimney connector and the appliance and combustible material.

Table 5. Fourteen Room Wall-Ceiling Systems Tested

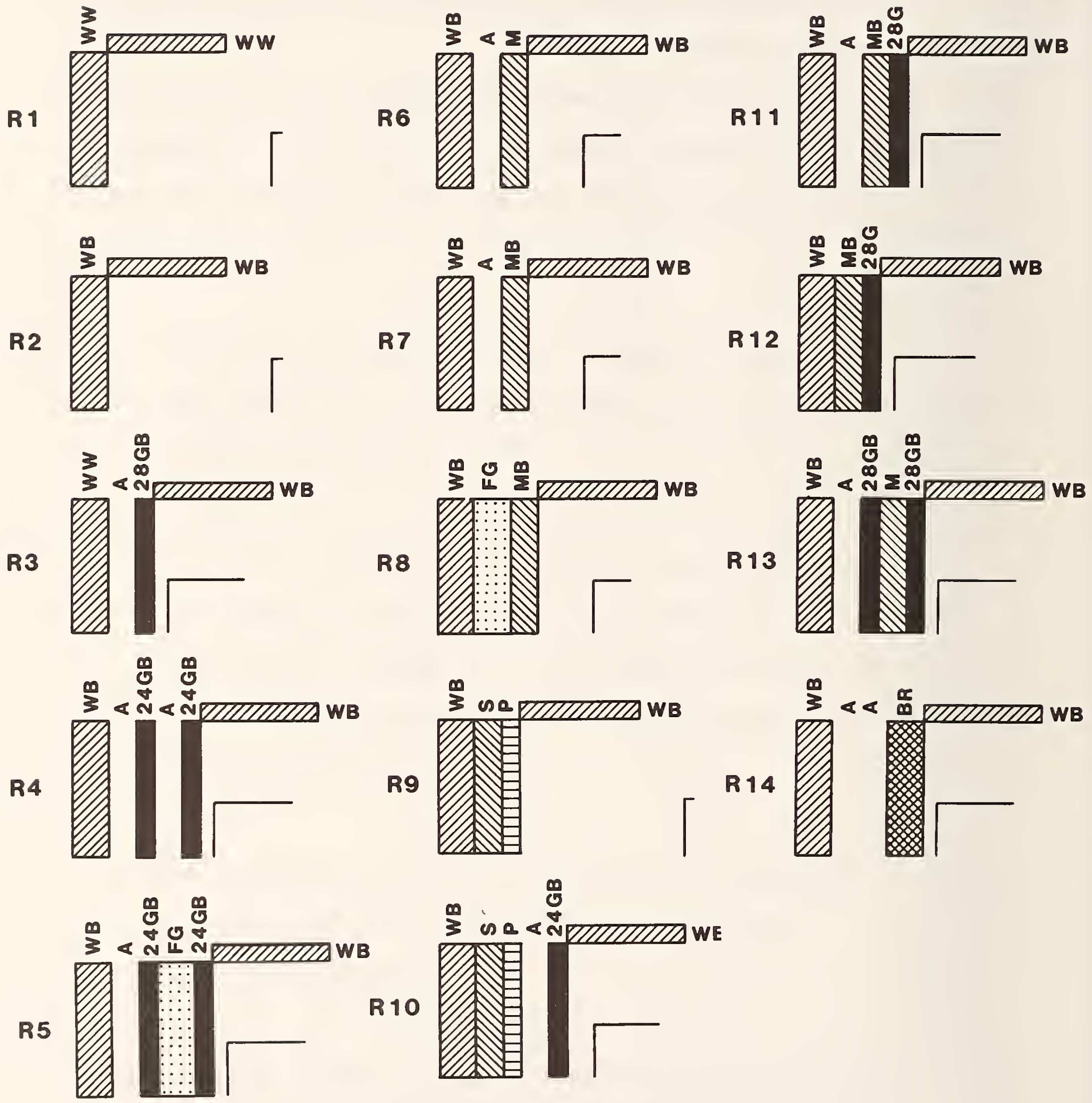


Table 6. Range of Surface Temperature Rise Along the Horizontal and Vertical Lines of Room Walls

HORIZONTAL

System	Wall Clearance (mm/in)	Stove Temperature 350°C	400°C	450°C
R1	914/36	23 - 47	34 - 65	44 79
	610/24	30 - 73[a]	39 - 96	45 111
	457/18	29 - 91	39 - 122	46 143
	305/12	27 - 117	37 - 155	43 179
R2	914/36	24 - 53	35 - 68	43 - 81
	610/24	29 - 80	39 - 100	48 - 122
	457/18	29 - 100	40 - 126	48 - 151
R3	305/12	2 - 32	3 - 43	1 - 52
	152/6	3 - 29	2 - 37	5 - 47
	76/3	4 - 26	4 - 35	8 - 43
R4	152/6	7 - 25	8 - 36	10 - 47
	76/3	5 - 22	8 - 31	9 - 39
R5	152/6	0 - 25	0 - 36	0 - 41
	76/3	0 - 21	0 - 29	0 - 34
R6	305/12	8 38	18 51	14 66
	152/6	10 50	10 60	16 72
	76/3	10 65	19 76	21 84
R7	457/18	29 43	10 55	
	305/12	10 39	15 47	40 55
	152/6	10 54	16 67	32 76
	76/3		16 77	18 86
R8	457/18	7 - 39	14 47	19 67
	305/12	10 - 42	12 68	— —
	152/6	9 - 72	9 90	22 107
	76/3	20 - 86	13 100	16 124
R9	1.06m/42	— —	28 - 55	34 68
	914/36	29 - 51	30 - 64	36 74
R10	305/12	3 - 45	6 - 54	8 71
	152/6	3 - 36	5 - 49	7 71
	76/3	3 - 50	8 - 74	15 94
R11	305/12	0 - 39	0 - 50	0 61
	152/6	0 - 34	0 - 49	0 60
	76/3	0 - 26	0 - 38	0 48
R12	305/12	0 - 39	0 - 55	0 64
	152/6	0 - 34	0 - 44	0 58
	76/3	0 - 16	0 - 36	0 48
R13	305/12	0 - 27	0 - 40	0 44
	152/6	0 - 22	0 - 27	0 35
	76/3	0 - 46	0 - 18	0 54
R14	914/36	0 - 10	0 - 12	0 14
	610/24	0 - 18	0 - 23	0 23
	305/12	— —	0 - 37	0 42
	229/9	— —	0 - 43	0 48
	152/6	0 - 41	0 - 53	0 56
	76/3	0 - 43	0 - 61	0 68

Note: [a] Underlined temperatures exceed code limits.

Table 6. Continued

VERTICAL

System	Wall Clearance (mm/in)	Stove Temperature		
		350°C	400°C	450°C
R1	914/36	30 - 35	35 - 47	39 - 59
	610/24	30 - 50	37 - 70	42 - 77
R2	914/36	30 - 50	32 - 66	
	610/24	30 - 79	38 - 98	
R3	305/12	0 - 32	1 - 43	0 - 58
	152/6	0 - 34	0 - 41	0 - 109
	76/3	0 - 39	0 - 116	0 - 161
R4	152/6	0 - 4	0 - 5	0 - 6
	76/3	0 - 6	0 - 7	0 - 9
R5	152/6	0 - 5	0 - 5	0 - 6
	76/3	0 - 6	0 - 7	0 - 9
R6	305/12	6 - 39	7 - 48	9 - 54
	152/6	1 - 55	2 - 63	8 - 76
	76/3	0 - 69	0 - 79	0 - 87
R7	457/18	4 - 33	4 - 37	
	305/12	5 - 42	5 - 35	5 - 42
	152/6	3 - 58	5 - 48	7 - 56
	76/3		6 - 55	8 - 63
R8	457/18	0 - 22	0 - 52	0 - 35
	305/12	0 - 49	0 - 67	0 - 62
	152/6	0 - 84	0 - 74	0 - 69
R9	1.06m/42		35 - 74	31 - 80
	914/36	22 - 53	25 - 64	32 - 79
R10	305/12	5 - 31	3 - 39	6 - 53
	152/6	0 - 31	1 - 56	4 - 82
	76/3	0 - 59	0 - 80	0 - 107
R11	305/12	0 - 19	0 - 20	0 - 18
	152/6	0 - 21	0 - 25	0 - 27
	76/3	0 - 22	0 - 28	0 - 33
R12	305/12	0 - 19	1 - 24	1 - 26
	152/6	3 - 23	5 - 26	4 - 29
	76/3	1 - 24	4 - 29	5 - 34
R13	305/12	0 - 18	0 - 24	0 - 28
	152/6	0 - 21	0 - 26	0 - 32
	76/3	0 - 32	0 - 38	0 - 41
R14	610/24	0 - 18	0 - 21	0 - 22
	305/12	— —	3 - 32	0 - 43
	229/9	-- --	4 - 44	3 - 52
	152/6	3 - 48	4 - 54	5 - 59
	76/3	3 - 46	4 - 67	4 - 75

Table 7. Minimum Clearances Needed Between Appliance and Exposed Wall Surfaces to Meet Code Requirements

System No.	Wall	Ceiling	Stove Temperatures 350°C	400°C	450°C
			Minimum Clearance (mm/in)		
R1	(WW)	WW	914/36	914/36	> 914/36
R2	(WB)	WB	914/36	> 914/36	> 914/36
R3	(WW, A, 28GB)	WB	76/3	152/6	> 305/12
R4	(WB, A, 24GB, A, 24GB)	WB	76/3	76/3	76/3
R5	(WB, A, 24GB, FG, 24GB)	WB	76/3	76/3	76/3
R6	(WB, A, M)	WB	305/12	> 305/12	> 305/12
R7	(WB, A, MB)	WB	305/12	457/18	> 305/12
R8	(WB, FG, MB)	WB	305/12	> 457/18	> 457/18
R9	(WB, S, P)	WB	914/36	>1067/42	>1067/42
R10	(WB, S, P, A, 24GB)	WB	152/6	> 305/12	> 305/12
R11	(WB, A, MB, 28G)	WB	76/3	76/3	> 305/12
R12	(WB, MB, 28G)	WB	76/3	> 305/12	> 305/12
R13	(WB, A, 28GB, MB, 28GB)	WB	76/3	76/3	76/3
R14	(WB, AA, BR)	WB	76/3	229/9	305/12

Table 8. Temperatures At Overfire Conditions for Systems Showing High Ceiling Surface Temperatures

			Stove Temperature Wall Clearance mm (in)			
System No.	Wall	Ceiling	400 305/12 (°C)	450 76/3 (°C)	450 152/6 (°C)	450 305/12 (°C)
R6	(WB, A, M)	(WB)	68[a]	-	-	-
R11	(WB, A, MB, 28GB)	(WB)	67	-	71	77
R12	(WB, MB, 28G)	(WB)	68	-	-	-
R13	(WB, A, 28GB, MB, 28GB)	(WB)	67	67	69	74
R14	(WB, AA, BR)	(WB)	-	-	-	69

Note: [a] Acceptance level 65°C

Table 9. Reduction of Appliance Clearance with Specified Forms of Protection

Clearance Reduction System Applied to and Covering all Combustible surfaces within the distance specified as required clearance with no protection.	Minimum Allowable Clearance (Percent) of Unprotected Clearance		When the required clearance with no protection is 914 mm (36 in), the clearances below are the Minimum Allowable clearance.	
	As Wall Protector	As Ceiling Protector	As Wall Protector (mm/in)	As Ceiling Protector (mm/in)
(a) 90 mm (3-1/2 in) thick masonry wall without ventilated air space	67%	-	610/24	-
(b) 13 mm (1/2 in) thick insulation board over 25 mm (1 in) glass fiber or mineral wool batts	50%	67%	457/18	610/24
(c) 0.61 mm (0.024 in) (24 gauge) sheet metal over 25 mm (1 in) glass fiber or mineral wool batts reinforced with wire, or equivalent on rear face with ventilated air space	33%	50%	305/12	457/18
(d) 90 mm (3-1/2 in) thick masonry wall with ventilated air space	33%	-	305/12	-
(e) 0.61 mm (0.024 in) (24 gauge) sheet metal with ventilated air space	33%	50%	305/12	457/18
(f) 13 mm (1/2 in) thick insulation board with ventilated air space	33%	50%	305/12	457/18
(g) 0.61 mm (0.024 in) (24 gauge) sheet metal with ventilated air space over 0.61 (0.024 in) (24 gage) sheet metal with ventilated air space	17%	33%	152/6	305/12
(h) 25 mm (1 in) glass fiber or mineral wool batts sandwiched between two sheets 0.61 mm (0.024 in) (24 gauge) sheet metal with ventilated space.	17%	33%	152/6	305/12

NOTES - Table 9

[1] Spacers and ties shall be of noncombustible material. No spacers or ties shall be used directly behind appliance or connector.

[2] With all clearance reduction systems using a ventilated air space, adequate air circulation shall be provided as described. There shall be at least 25 mm (1 in) between the clearance reduction system and combustible walls and ceilings for clearance reduction systems using a ventilated air space.

[3] Mineral wool batts (blanket or board) shall have a minimum density of 128 kg/m^3 (8 lb per ft^3) and have a minimum melting point of 816°C (1500°F).

[4] Insulation material used as part of clearance reduction system shall have a thermal conductivity of 1.0 (BTU-in)/(sq ft-hr-°F) or less.

[5] If a single wall connector passes through the masonry wall, there shall be at least 13 mm (1/2 in) of open ventilated air space between the connector and the masonry.

[6] There shall be at least 25 mm (1 in) between the appliance and the protector. In no case shall the clearance between the appliance and the wall surface be reduced below that allowed in the table.

[7] Clearances in front of the loading door and/or ash removal door of the appliance shall not be reduced from those required with no protection.

[8] All clearances and thicknesses are minimums, larger clearances and thicknesses are acceptable.

[9] To calculate the minimum allowable clearance, the following formula may be used: $C_{pr} = C_{un} \times (1-R/100)$; C_{pr} is the minimum allowable clearance, C_{un} is the required clearance with no protection, and R is the maximum allowable reduction in clearance.

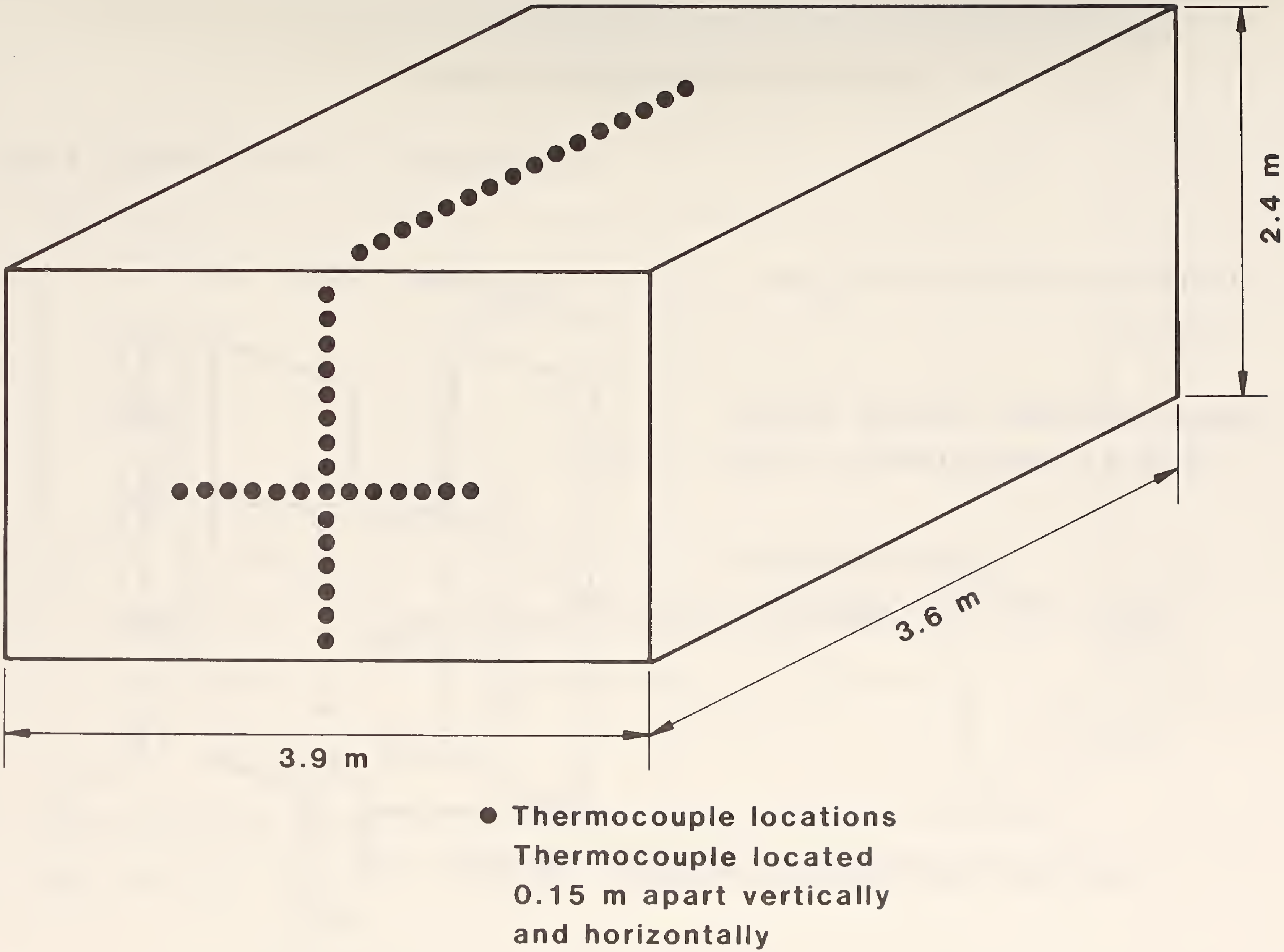


Figure 15. Thermocouple Locations on Exposed Wall and Ceiling

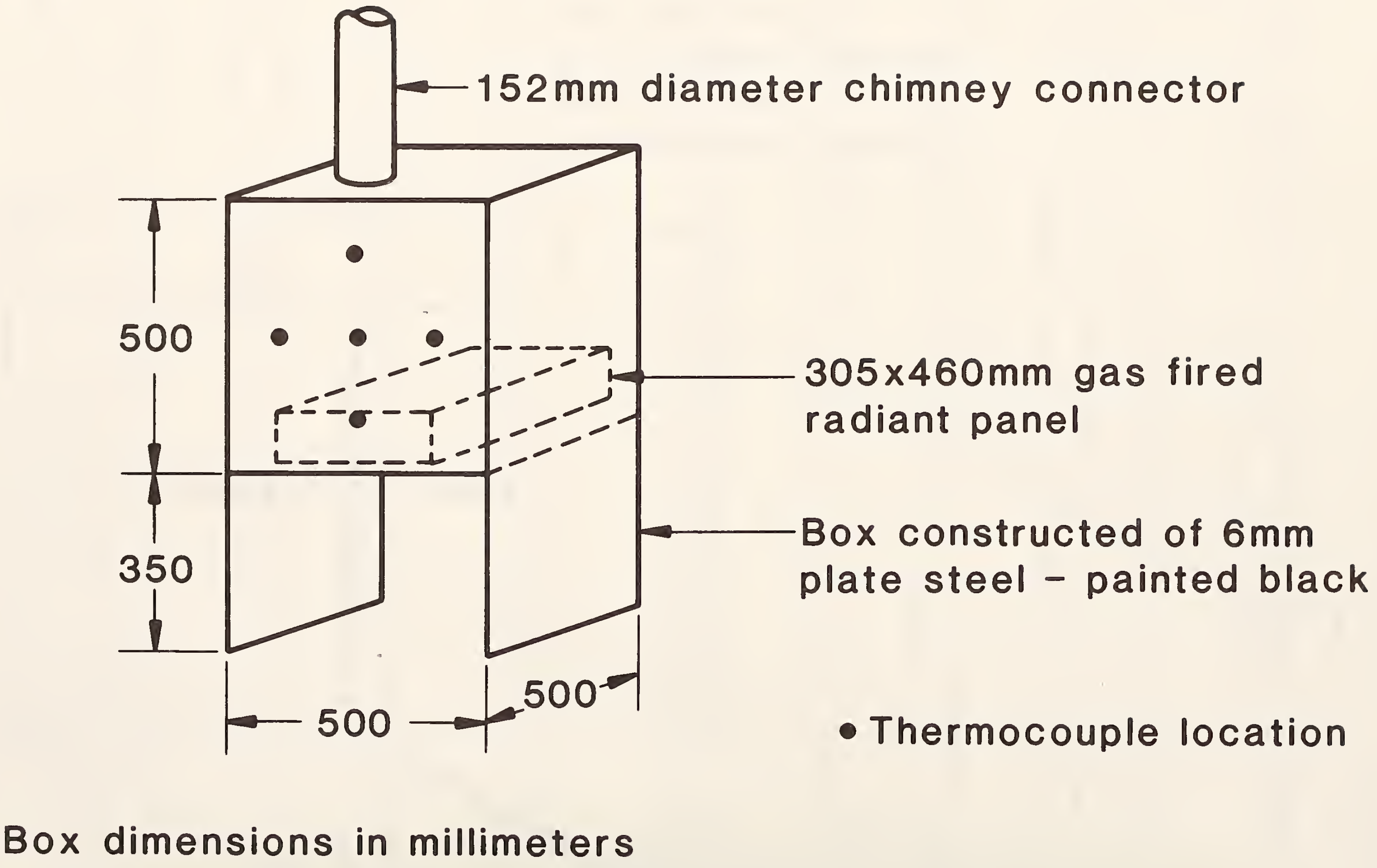

152mm diameter chimney connector
305x460mm gas fired radiant panel
Box constructed of 6mm plate steel - painted black
● Thermocouple location
500
350
500
500
Box dimensions in millimeters

Figure 16. Appliance Construction Details

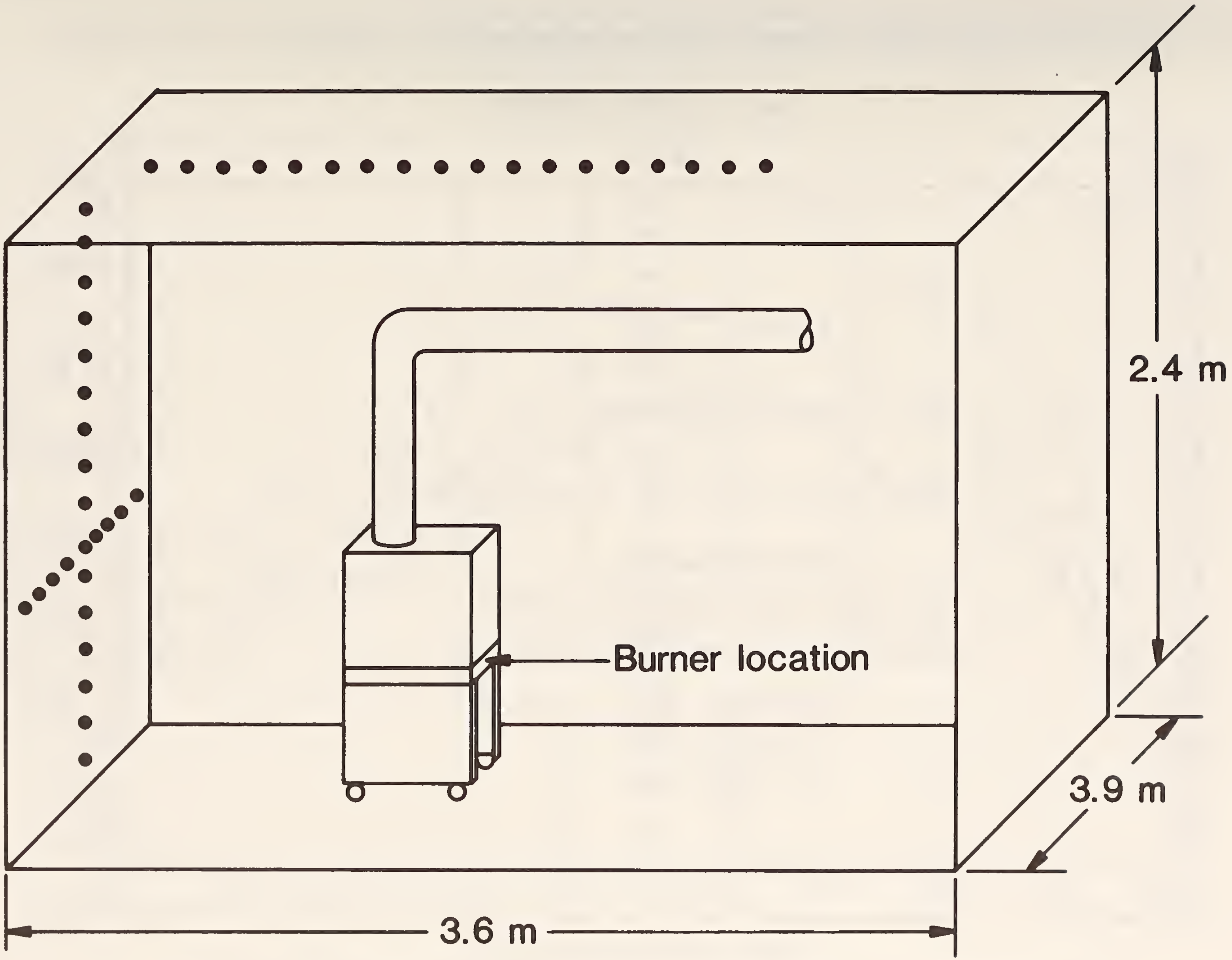


Figure 17. Test Apparatus - Arrangement for Minimum Clearance Tests

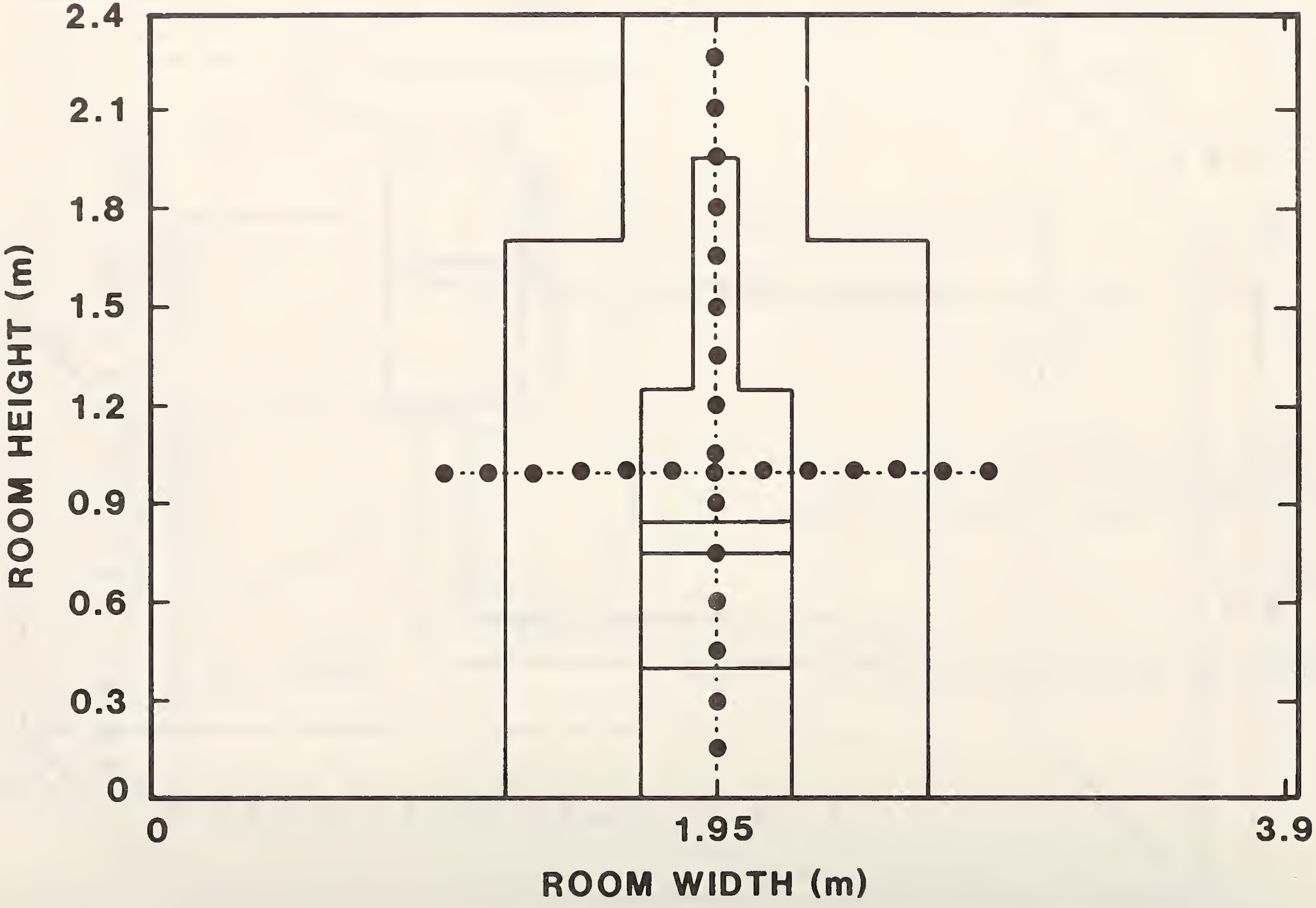

RELATION OF APPLIANCE TO PROTECTOR PLATE SYSTEM AND THERMOCOUPLES ON WALL SURFACE

Figure 18. Relation of Appliance to Protector Plate System and Thermocouples on Wall Surface

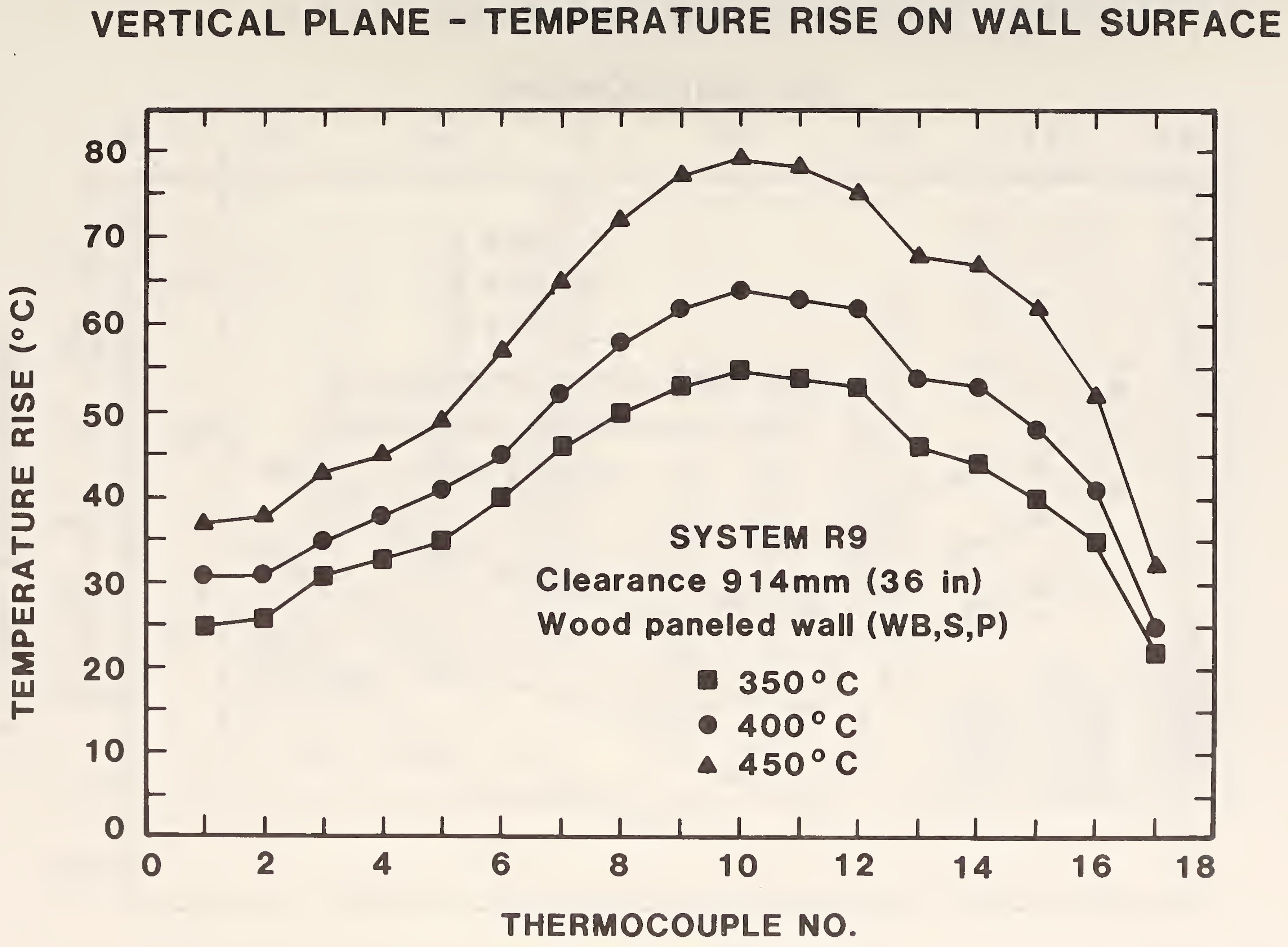


Figure 19. Vertical Plane - Temperature Rise on Wall Surface

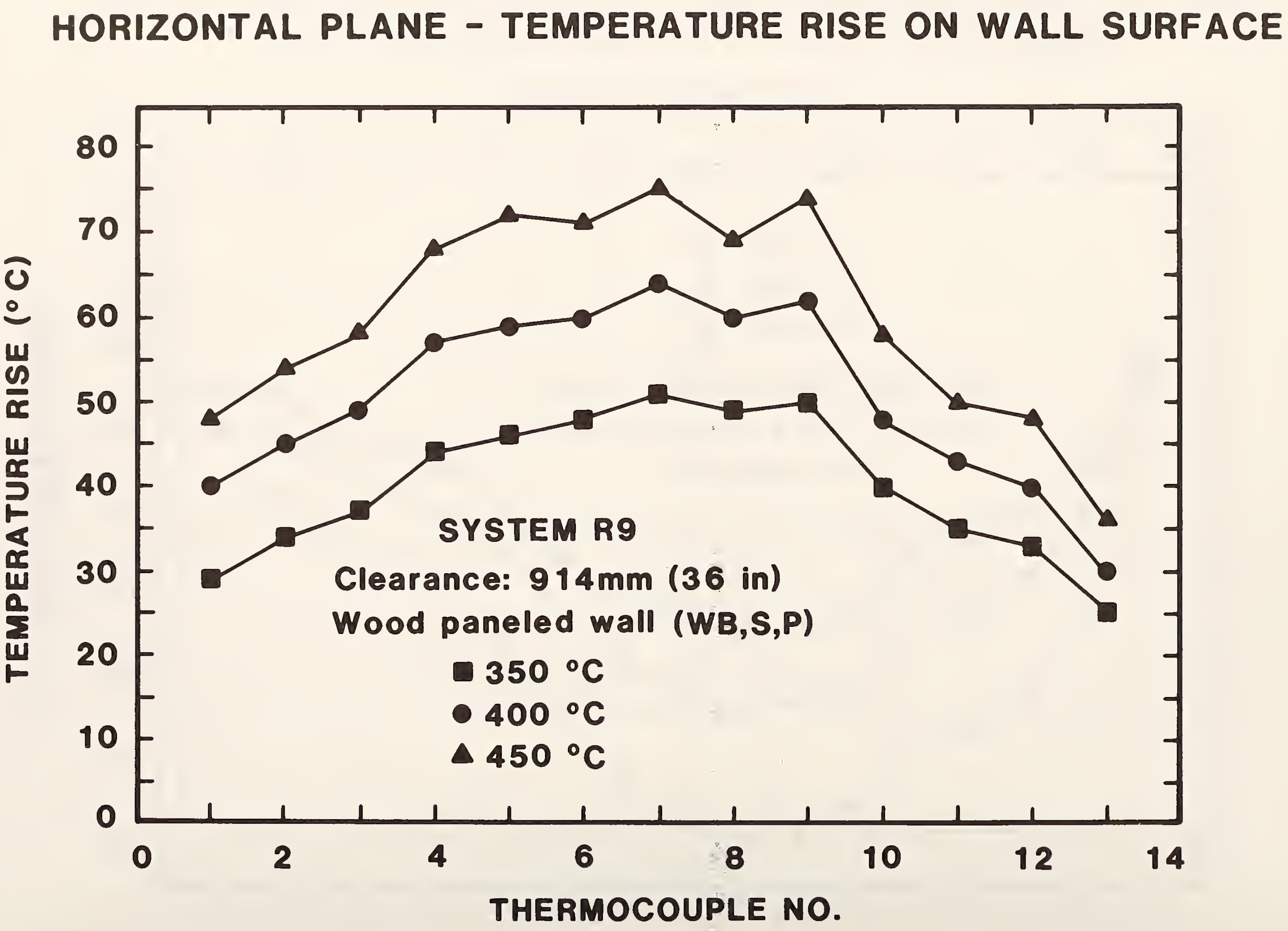


Figure 20. Horizontal Plane - Temperature Rise on Wall Surface

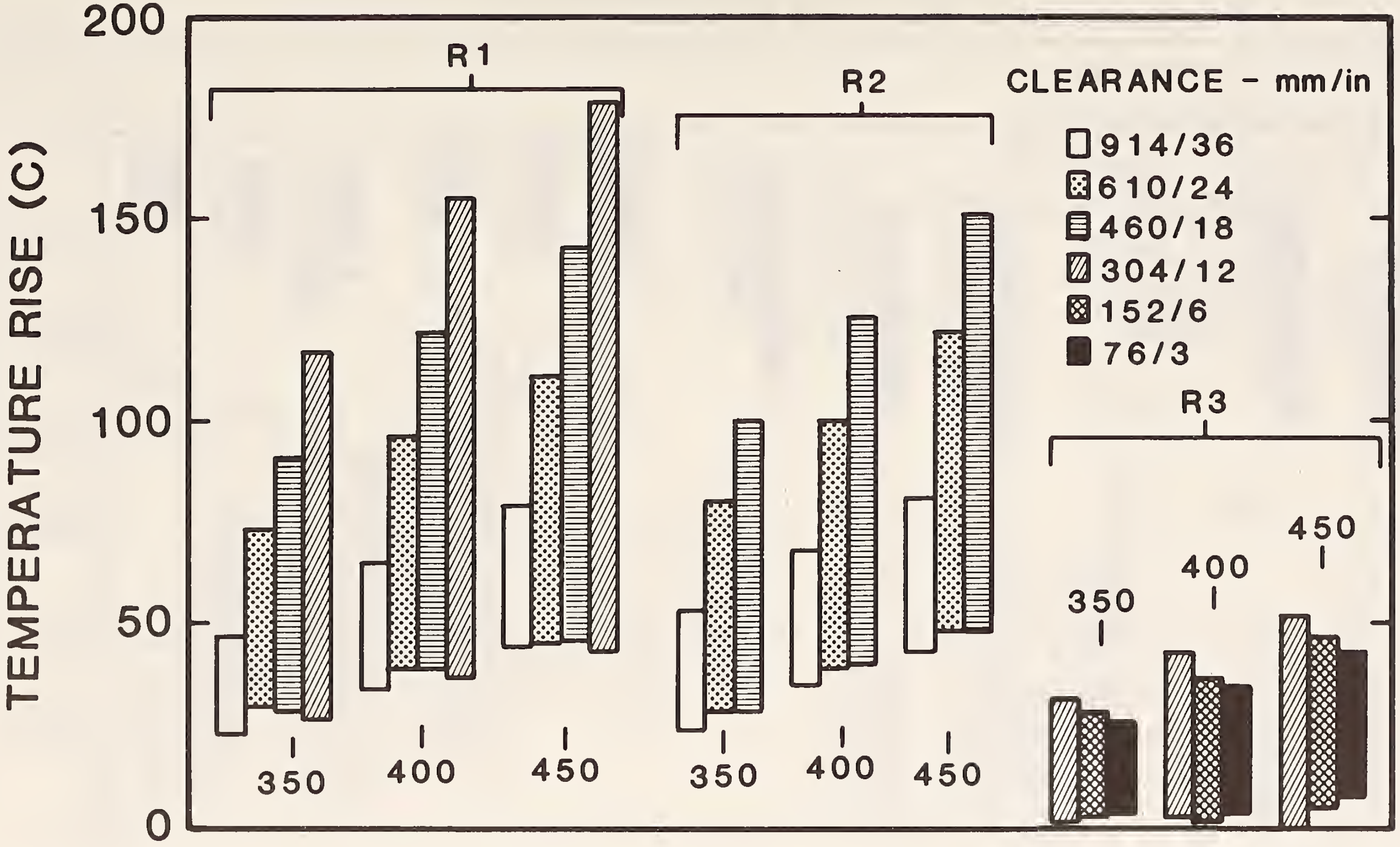


Figure 21. Range of Temperature Rise Along the Horizontal Plane of a Room Wall (Systems R1 - R3)

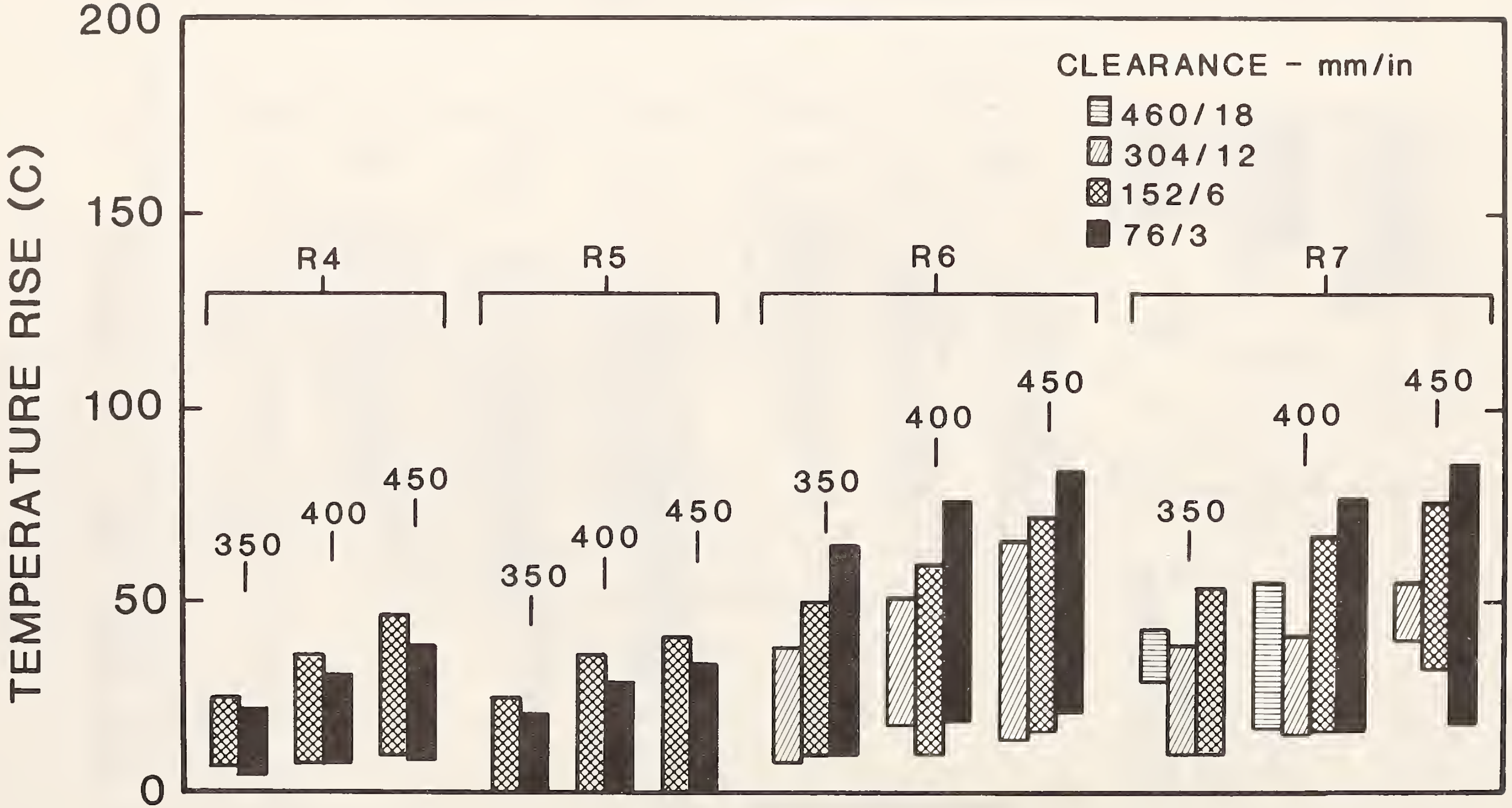


Figure 22. Range of Temperature Rise Along the Horizontal Plane of a Room Wall (Systems R4 - R7)

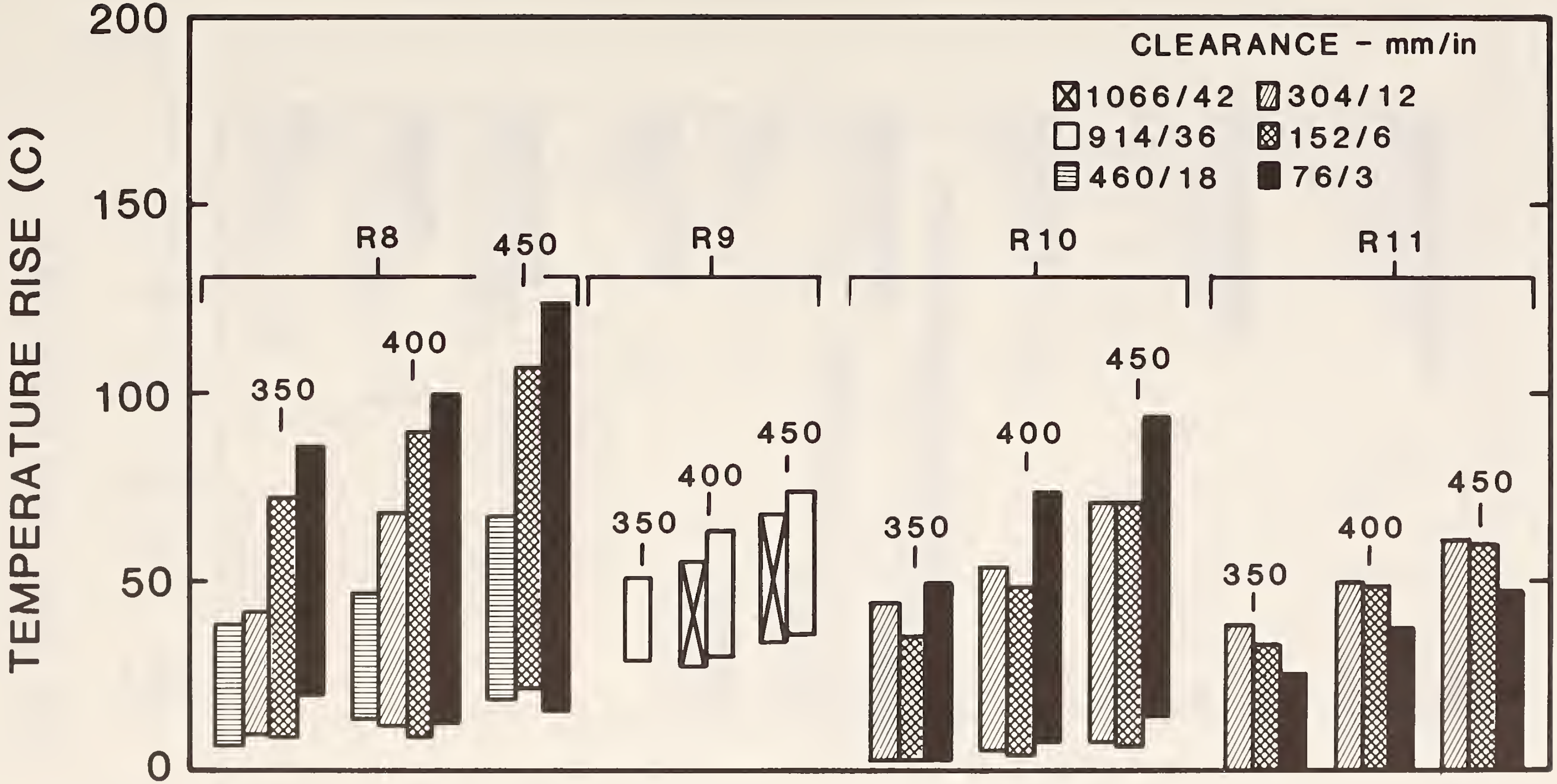


Figure 23. Range of Temperature Rise Along the Horizontal Plane of a Room Wall (Systems R8-R11)

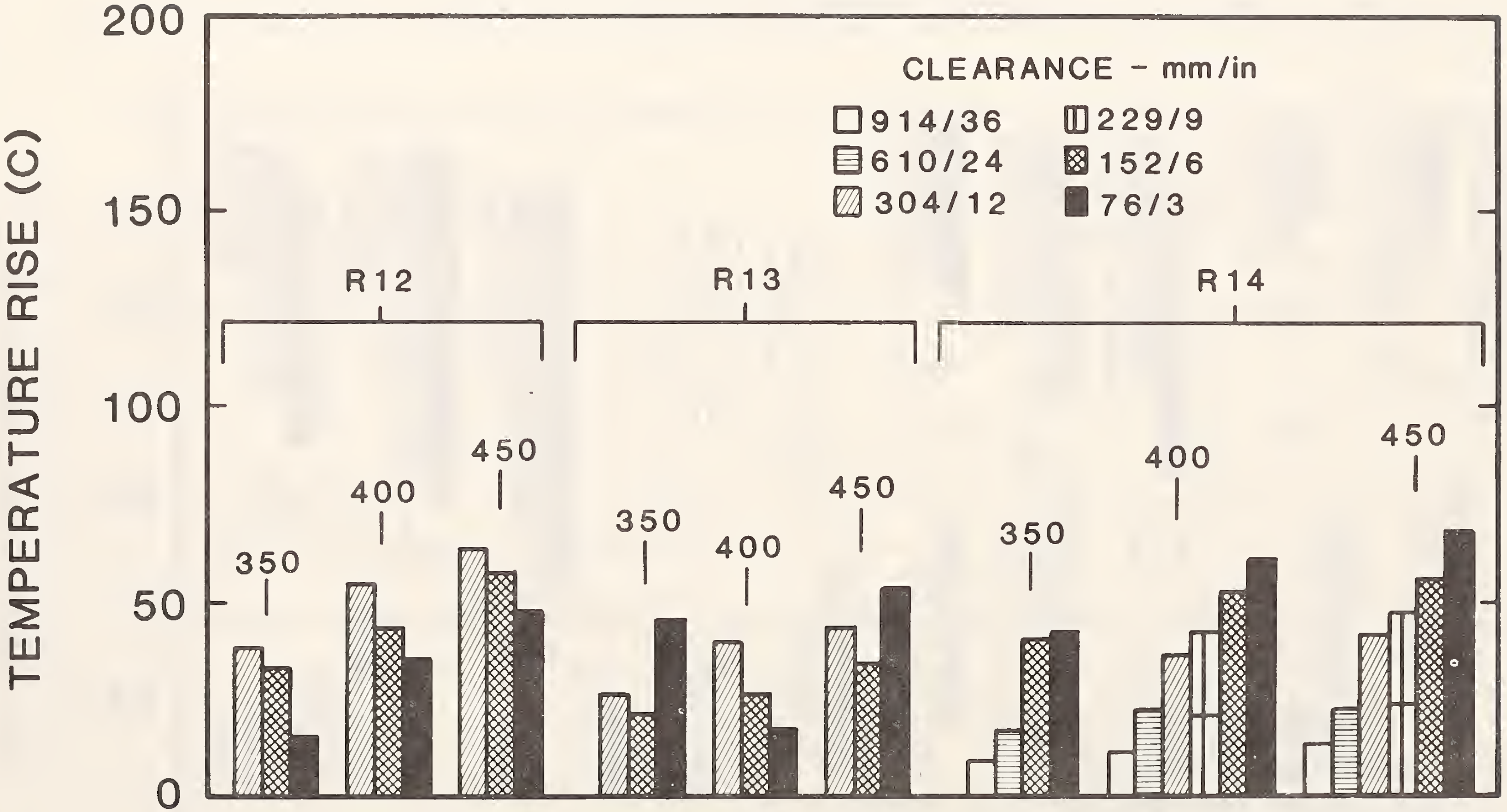


Figure 24. Range of Temperature Rise Along the Horizontal Plane of a Room Wall (Systems R12 - R14)

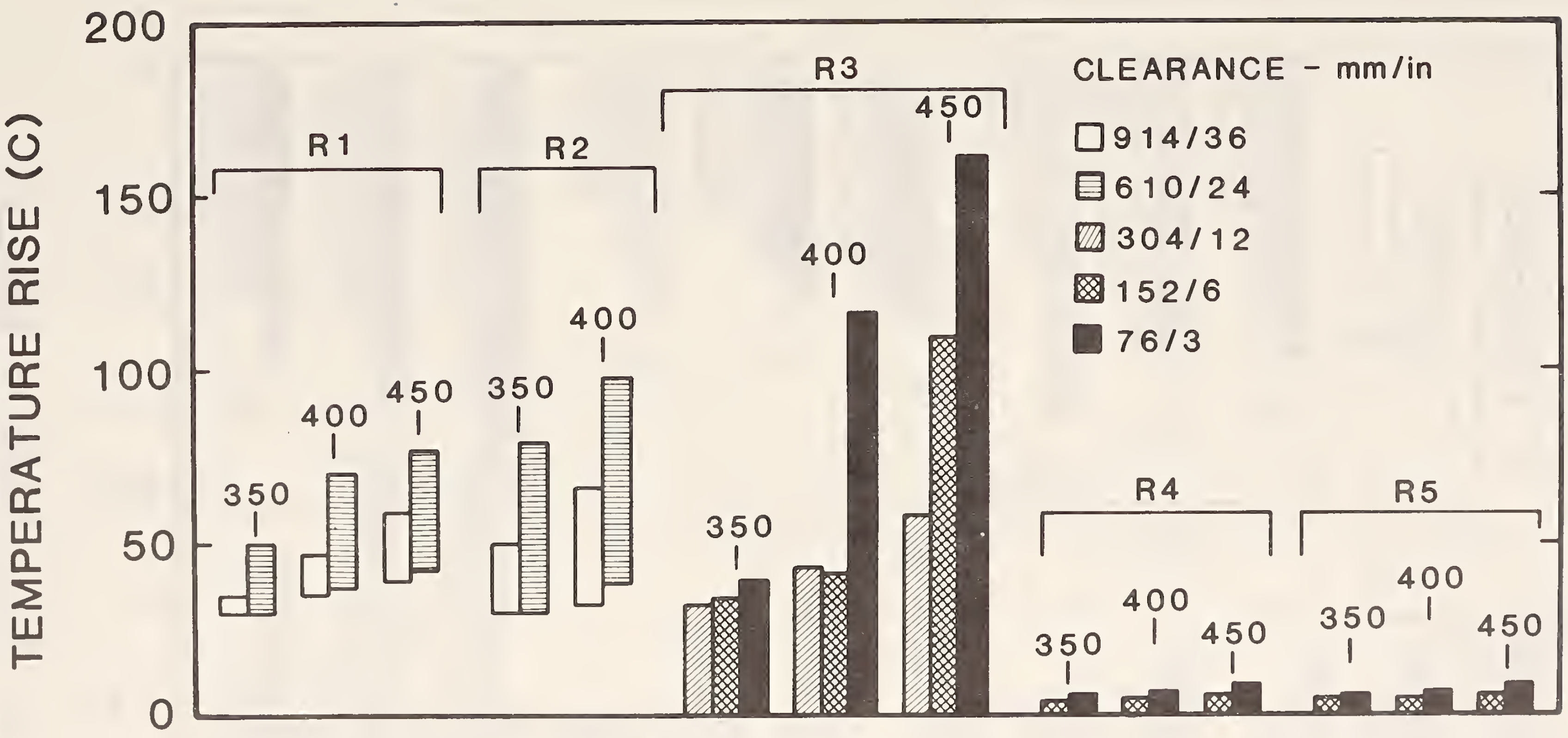


Figure 25. Range of Temperature Rise Along the Vertical Plane of a Room Wall (Systems R1 - R5)

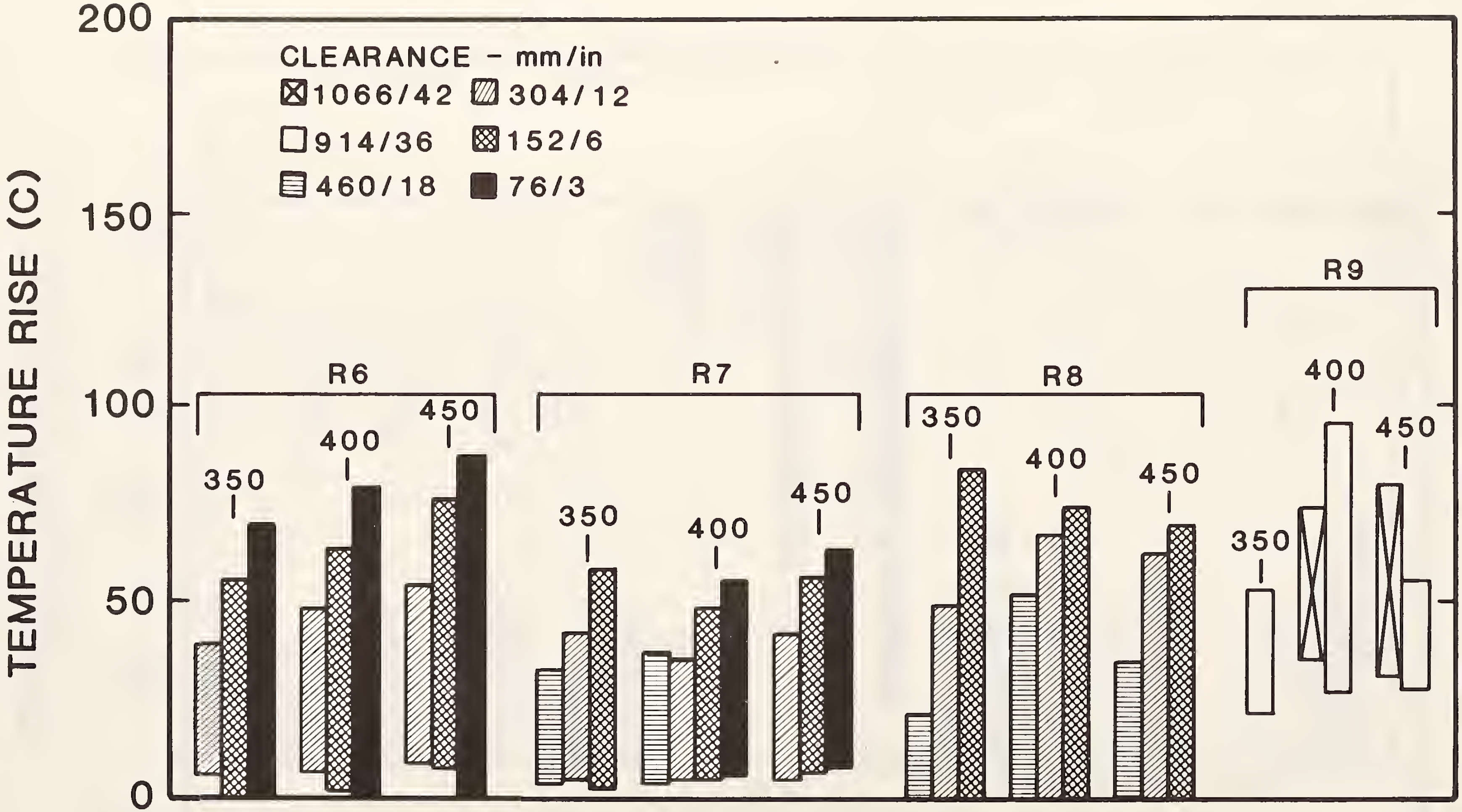


Figure 26. Range of Temperature Rise Along the Vertical Plane of a Room Wall (Systems R5 - R9)

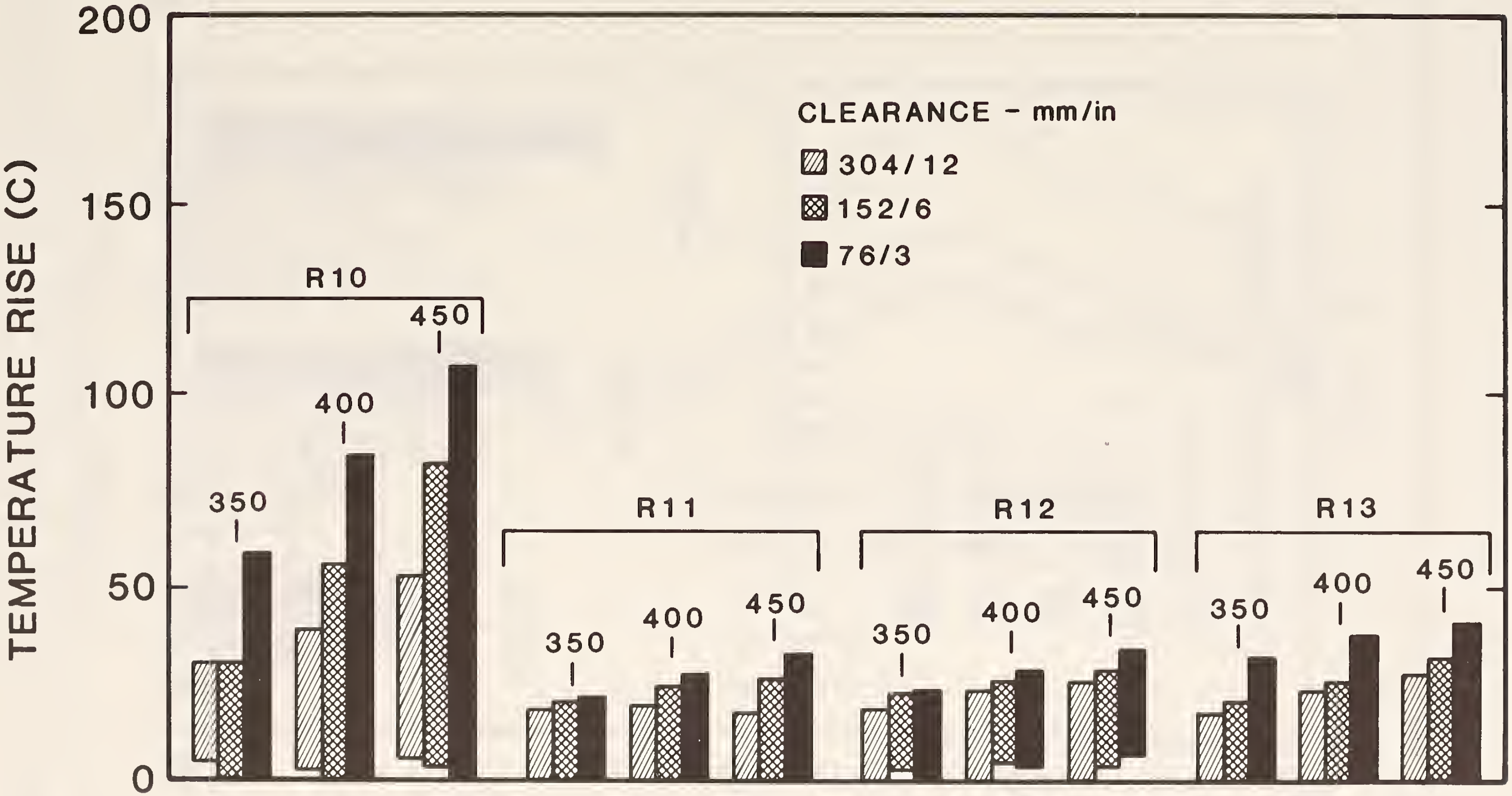


Figure 27. Range of Temperature Rise Along the Vertical Plane of a Room Wall (Systems R10 - R13)

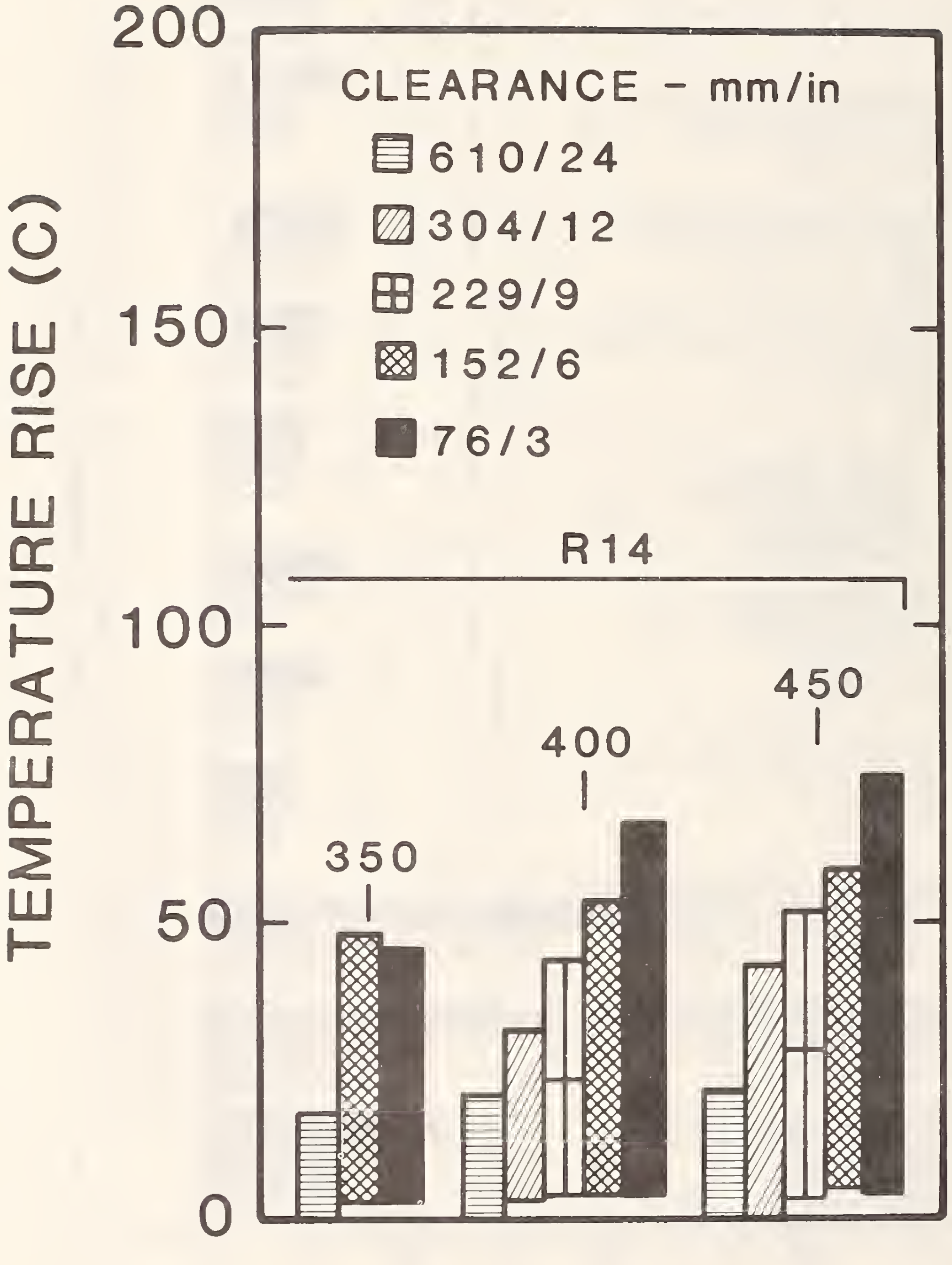


Figure 28. Range of Temperature Rise Along the Vertical Plane of a Room Wall (System R14)

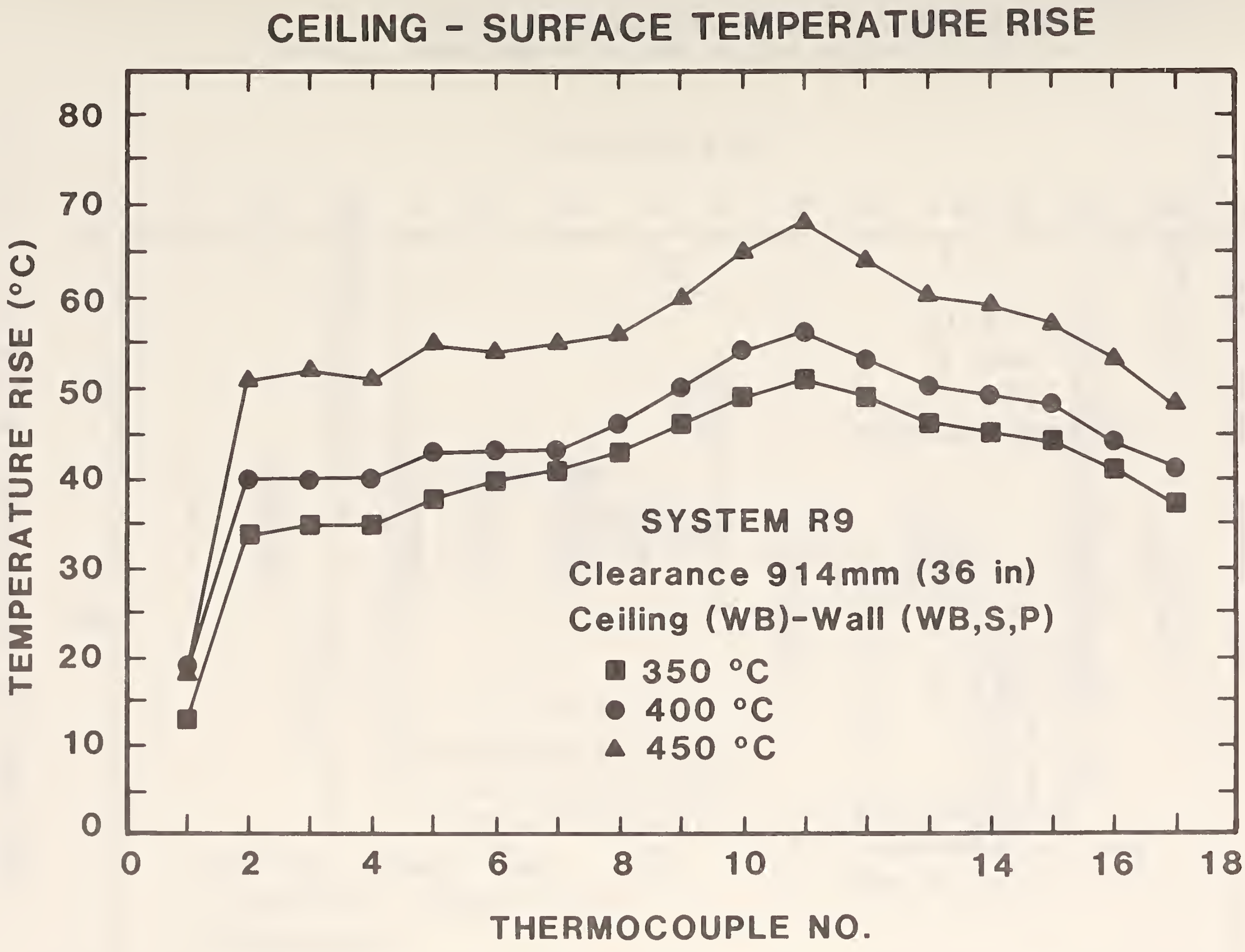


Figure 29. Typical Surface Temperature Rise on a Test Ceiling

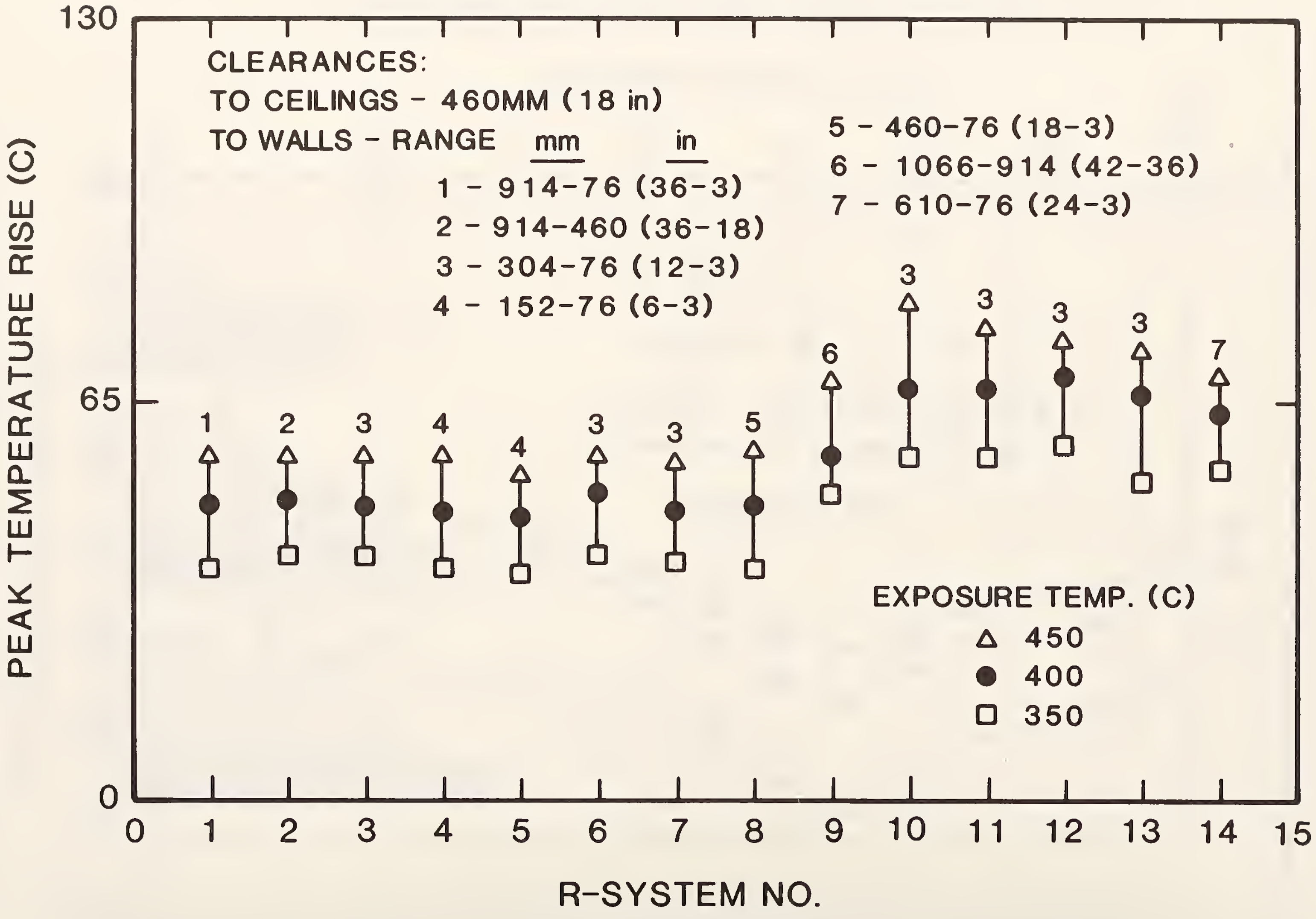


Figure 30. Peak Temperature Rise on Room Ceiling Exposed to a Chimney Connector from a Radiant Heating Appliance

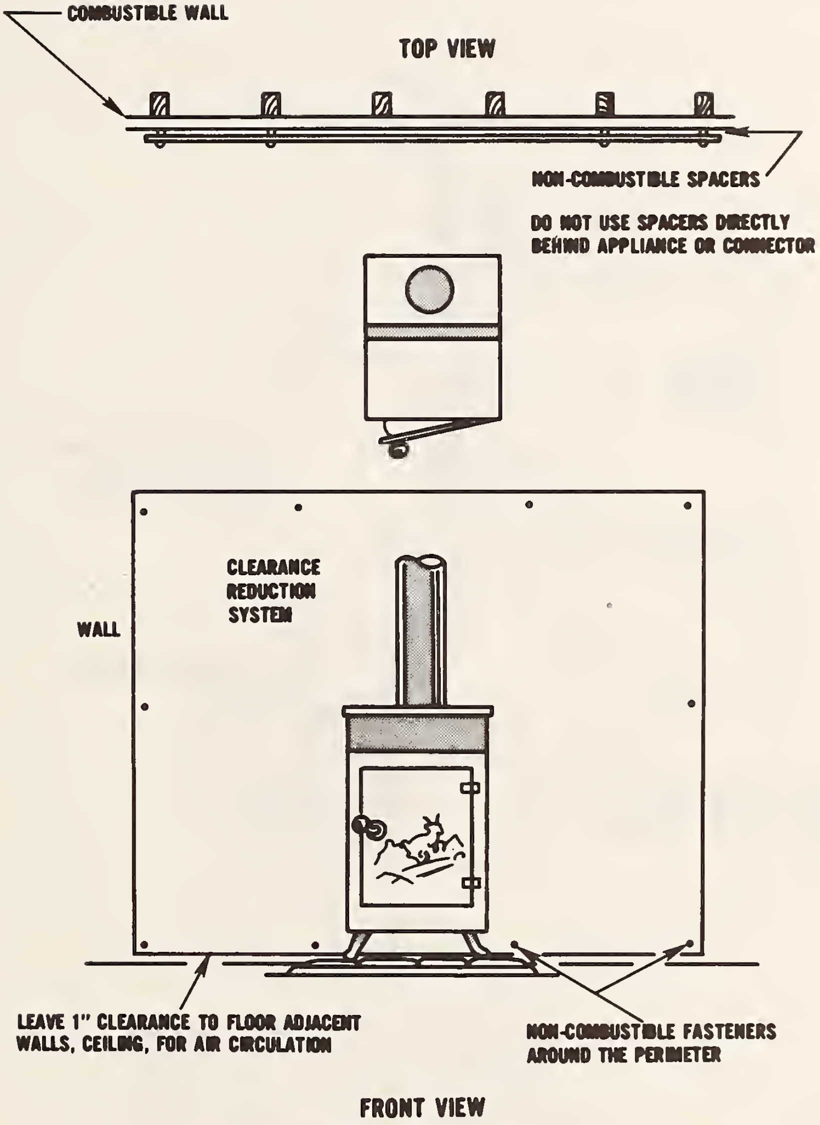

COMBUSTIBLE WALL
TOP VIEW
NON-COMBUSTIBLE SPACERS
DO NOT USE SPACERS DIRECTLY BEHIND APPLIANCE OR CONNECTOR
CLEARANCE REDUCTION SYSTEM
WALL
LEAVE 1" CLEARANCE TO FLOOR ADJACENT WALLS, CEILING, FOR AIR CIRCULATION
NON-COMBUSTIBLE FASTENERS AROUND THE PERIMETER
FRONT VIEW

Figure 31. Clearance Reduction System for Residential Heating Appliance

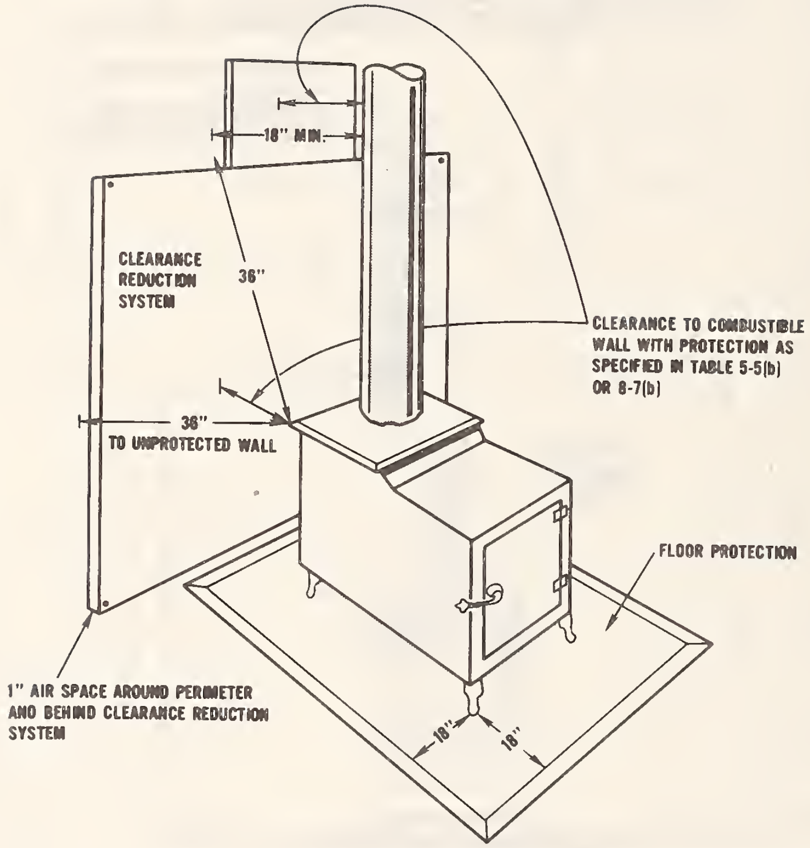
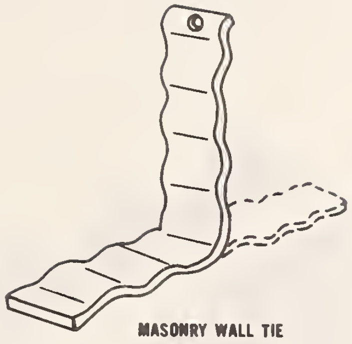
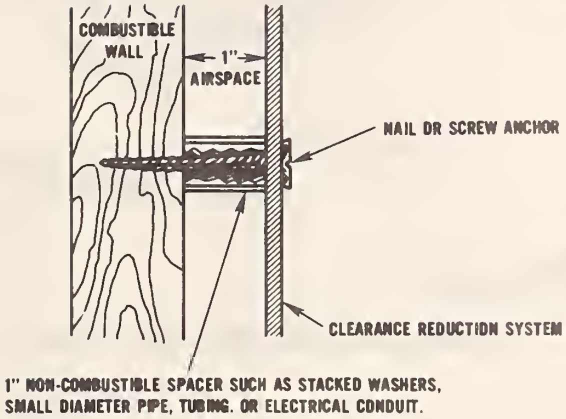

18" MIN.
CLEARANCE REDUCTION SYSTEM
36"
36"
TO UNPROTECTED WALL
CLEARANCE TO COMBUSTIBLE WALL WITH PROTECTION AS SPECIFIED IN TABLE 5-5(b) OR 8-7(b)
FLOOR PROTECTION
1" AIR SPACE AROUND PERIMETER AND BEHIND CLEARANCE REDUCTION SYSTEM
18"
18"

Figure 32. Clearance Reduction System for Residential Heating Appliance

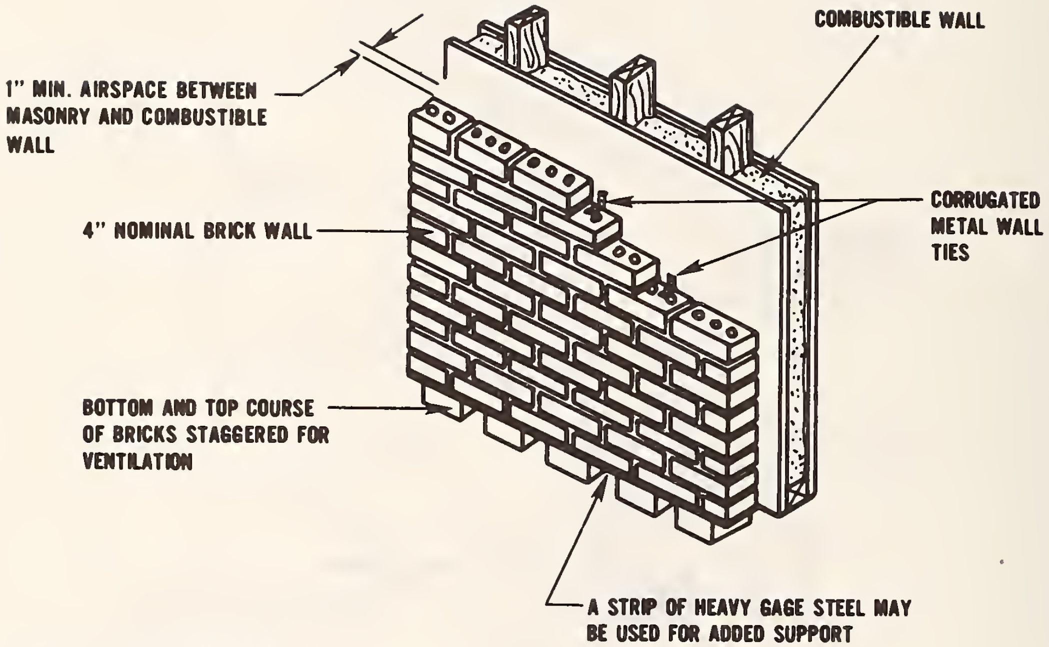



COMBUSTIBLE WALL
1"
AIRSPACE
NAIL OR SCREW ANCHOR
CLEARANCE REDUCTION SYSTEM
1" NON-COMBUSTIBLE SPACER SUCH AS STACKED WASHERS, SMALL DIAMETER PIPE, TUBING. OR ELECTRICAL CONDUIT.

MASONRY WALLS MAY BE ATTACHED TO COMBUSTIBLE WALLS USING WALL TIES.

DO NOT USE SPACERS DIRECTLY BEHIND APPLIANCE OR CONNECTOR.

Figure 33. Masonry Clearance Reduction System


COMBUSTIBLE WALL
1" MIN. AIRSPACE BETWEEN MASONRY AND COMBUSTIBLE WALL
4" NOMINAL BRICK WALL
CORRUGATED METAL WALL TIES
BOTTOM AND TOP COURSE OF BRICKS STAGGERED FOR VENTILATION
A STRIP OF HEAVY GAGE STEEL MAY BE USED FOR ADDED SUPPORT

Note: DO NOT PLACE MASONRY WALL TIES DIRECTLY BEHIND APPLIANCE OR CONNECTOR

MASONRY CLEARANCE REDUCTION SYSTEM

Figure 34. Non-Combustible Spaces for Clearances Systems

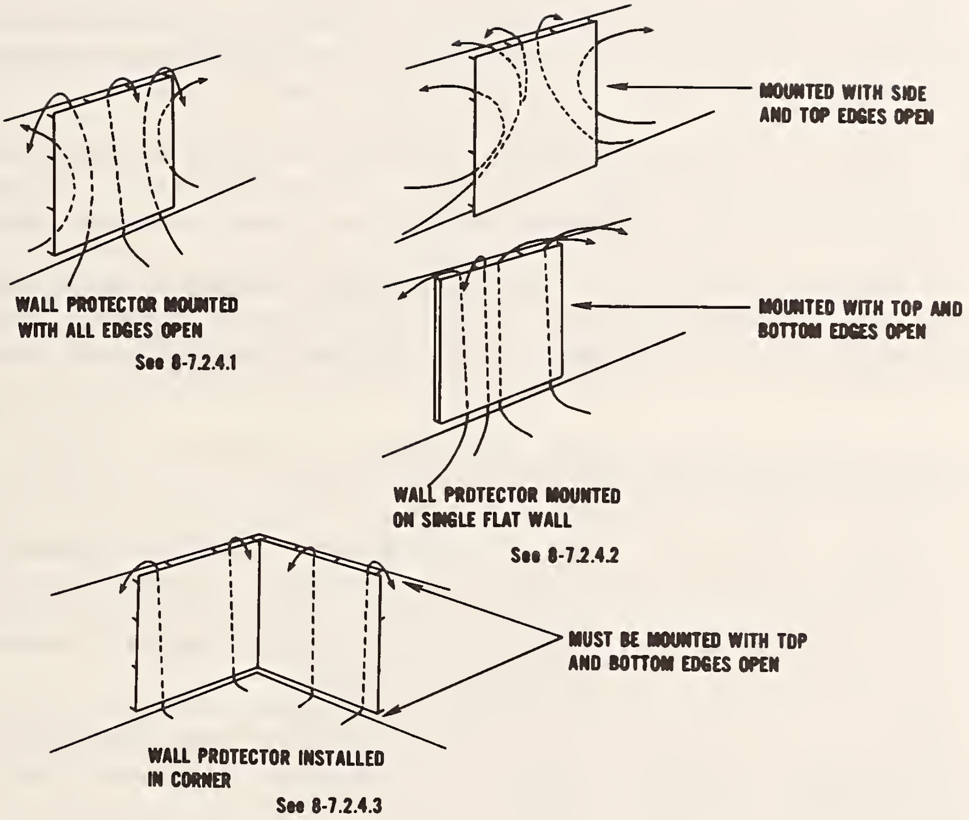


Figure 35. Air Movement Around Protector Plates or Panels

24. REFERENCES

[1] Peacock, R.D., A Review of Fire Incidents, Model Building Codes, and Standards Related to Wood-Burning Appliances, Nat. Bur. Stand. (U.S.), NBSIR 79-1731 (May 1979).

[2] Peacock, R.D., et al., Fire Safety of Wood-Burning Appliances, Part 1: State of the Art Review and Fire Tests, Volumes I and II, Nat. Bur. Stand. (U.S.), NBSIR 80-2140 (Nov. 1980).

[3] Peacock, R.D., A Review of Fire Incidents Related to Wood-Burning Appliances, Wood Energy Institute, Proceedings of Wood Heating Seminar IV, Portland, OR, March 21-24, 1979, 43-46.

[4] Shelton, J.W., Analysis of Fire Reports on File in the Massachusetts State Fire Marshal's Office Relating to Wood and Coal Heating Equipment, Nat. Bur. Stand. (U.S.), NBS-GCR-78-149 (Nov. 1978).

[5] The BOCA Basic Building Code/1981, Model Building Regulations for the Protection of Public Health, Safety and Welfare, Eighth Edition, Building Officials and Code Administrators International, Homewood, IL

[6] The BOCA Basic Mechanical Code/1981, Model Mechnical Regulations for the Protection of Public Health, Safety and Welfare, Fourth Edition, Building Officials and Code Administrators International, Homewood, IL (1981).

[7] The National Building Code, 1976 Edition, American Insurance Association, New York, NY (1976).

[8] Chimneys, Fireplaces, Vents and Solid Fuel Burning Appliances, NFPA 211-1984, National Fire Protection Associaton, Boston, MA (1978).

[9] Standard Building Code, 1982 Edition, Southern Building Code Congress, International, Inc., Birmingham, AL (1982).

[10] Amendments to the Standard Building Code, 1977 and 1978 Revisions to the 1976 Edition, Southern Building Code Congress, International, Inc., Birmingham, AL (1978).

[11] Uniform Building Code, 1982 Edition, International Conference Building Officials (1982).

[12] 1977 Supplement to the Uniform Building Code, U.B.C. Standards, Uniform Housing Code, Uniform Code for the Abatement of Dangerous Buildings and the Uniform Fire Code, International Conference of Building Officials (1982).

[13] Manual on Clearances for Heat Producing Appliances, NFPA 89M-1976, National Fire Protection Association, Quincy, MA (1978).

[14] Voight, G.Q., Fire Hazard of Domestic Heating Installations, Nat. Bur. Stand. (U.S.), NBS Research Paper RP596 (Sept. 1933).

[15] Neale, J.A., Clearances and Insulation of Heating Appliances, Underwriters Laboratories, Inc., UL Bulletin of Research #27 (Feb. 1943).

[16] Lawson, D.I., Fox, L.L., and Webster, C.T., The Heating of Panels by Flue Pipes, Fire Research Special Report No. 1, Fire Protection Association, London, England (1952).

[17] Lawson, D.I. and Simms, D.L., The Ignition of Wood by Radiation, British Journal of Applied Physics, Vol. 3, 288-292 (Sept. 1952).

[18] Shoub, H., Survey of Literature on the Safty of Residential Chimneys and Firepalces, Nat. Bur. Stand. (U.S.), NBS Misc. Pub. 252 (Dec. 1963).

[19] Prefabricated Metal Chimneys, National Bureau of Standards, Fire Research Section, unpublished reports to Federal Public Housing Authority (1941-1945).

[20] Temperatures Developed in Chimneys for Low Cost Houses, Nat. Bur. Stand. (U.S.), Tech. News Bull. 328 (Aug. 1944).

[21] Fox, L.L. and Whittaker, D., Some Measurements of Temperatures of Metal Flues of Domestic Heating Appliances, Journal of the Institution of Heating and Ventilation Engineers, Vol. 23, 183-192 (Aug. 1955).

[22] Standard for Chimneys, Factory-Built Residential Type and Building Appliance--UL 103, Underwriters Laboratories, Inc., Northbrook, IL, (March 1971).

[23] Peacock, R.D., et al, Fire Safety of Wood Burning Appliances, Part 1: State of the Art Review and Fire Tests, Nat. Bur. Stds. (U.S.), NBSIR 80-2140 (1980).

[24] Standard for Room Heaters, Solid Fuel Type--UL 1482, First Edition, Underwriters Laboratories, Inc., Northbrook, IL (Aug. 1979).

[25] Mitchell, N.D., New Light on Self-Ignition, NFPA Quarterly, Vol. 45, No. 2, 165-172 (Oct. 1951).

[26] MacLean, J.D., Effect of Heat on Properties and Serviceability of Wood: Experiments on Thin Wood Specimens, Forest Products Laboratory Report No. R1471, Madison, WI (1945).

[27] MacLean, J.D., Rate of Disintegration of Wood Under Different Heating Conditions, American Wood-Preservers Association (1951).

[28] McGuire, J.H., Limiting Safe Surface Temperature of Combustible Materials, Fire Technology, Vol. 5, No. 3 (Aug. 1969).

[29] Ignition and Charring Temperatures of Wood, Forest Products Laboratory Report No. 1464, Madison, WI (Jan. 1958).

[30] Shelton, J.W., Wood Heat Safety, Garden Way Publishing, Charlotte, VT (Sept. 1979).

[31] Matson, A.F., Dufori, R.E., and Breen, J.F., Performance of Type B Gas Vents for Gas-Fired Appliances, Part II, Survey of Available Information on Ignition of Wood Exposed to Moderately Elevated Temperatures, Underwriters Laboratories, Inc., Bulletin of Research, No. 51, Northbrook, IL (May 1959).

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5. AUTHOR(S)

Joseph J. Loftus, Richard D. Peacock

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

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and

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Washington, DC 20207

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

The Center for Fire Research in the National Bureau of Standards has evaluated the fire hazard potential associated with the installation and use of solid fuel burning appliances (and chimney connectors) in residential housing.

For this three-part study, mock-up and full scale room walls and ceilings were exposed to radiant energy from chimney connectors and an appliance operated under normal and overfire conditions at various distances or clearances from the room members. Peak surface temperature rise measurements were made on exposed and protected walls and ceilings and comparisons were made with surface temperature rise limitations established by building and fire codes.

In the testing program, a total of 19 different thermal barriers or protection systems were evaluated and a number were found capable of providing adequate thermal protection. Particularly effective were those systems which used a sheet metal plate or two sheet metal plates with an insulative layer between them mounted in front of a wall or ceiling and separated from the room surface by a 25 mm (1 in) air space. This provision for air to circulate freely between a room member and its protector proved to be an extremely important factor in providing for increased fire safety.

Based on these findings, recommendations are made which building and fire code officials may find useful in preparing fire safety codes and regulations designed to protect the consumer from personal and property damage caused by unwanted fires.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

ceilings; chimneys; fire codes; fire protection; fire tests; interior finishes; radiant energy; residential buildings; stoves; walls.

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